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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Patentee:	James Kenneth Aragones et al.
Patent No.:	6,799,154 B1
Issued:	September 28, 2004
Title:	SYSTEM AND METHOD FOR PREDICTING THE TIMING OF FUTURE SERVICE EVENTS OF A PRODUCT

Attention: Certificate of Correction Branch
Commissioner for Patents
Alexandria, VA 22313-1450

COVER LETTER

SIR:

Enclosed are the following documents for the above-identified patent:

1. A request for Certificate of Correction under 37 CFR 1.322.
2. A PTO Form 1050 Certificate of Correction.
3. A copy of the patent application as originally filed without drawings.
4. A copy of the issued patent.
5. A copy of the only amendment to the claims submitted in this case.

Respectfully submitted,

Penny A. Clarke
Registration No. 46,627
Telephone (518) 387-5349

Schenectady, New York

Dated: Feb. 3, 2005

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S I R:

In accordance with 35 U.S.C.§254 and 37 C.F.R.§1.322, Patentee respectfully requests that the United States Patent and Trademark Office issue a certificate of correction for mistakes in the above identified patent, incurred through the fault of the Office, where mistakes are clearly disclosed in the records of the Office.

The patent contains an error in Claim 1, Column 11, Line 9 and 10 reads "distributions and performance life distributions plurality."

Claim 1, Column 11, Line 9 and 10 of the patent should read as follows:

"distributions and performance life distributions."

The patent contains an error in Claim 17, Column 11, Line 5 reads "end a plurality of performance information for the"

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The patent contains an error in Claim 17, Column 12, Line 22 and 23 reads "distributions and performance life distributions plurality of compartment."

Claim 17, Column 12, Line 22 and 23 Should read "distributions and performance life distributions."

The patent contains an error in Claim 21, Column 12, Line 1 reads "The system according to claim 17, wherein the pre-"

Claim 21, Column 12, Line 1 should read "The system according to claim 20, wherein the pre-"

A copy of the patent application as filed is enclosed for your convenience, as is a copy of the only Amendment filed in this case. These document that the errors were made by the Office and not by the Patentee.

Since the mistake was made by the Office and not by the Patentee, and is of consequence, and is clearly disclosed in the records of the Office, Patentee requests that the Office issue a certificate of correction without any fees charged to the Patentee.

If there are any questions regarding this matter please contact me.

Respectfully submitted,

Penny A. Clarke

Schenectady, New York

Dated: Feb. 3, 2005

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Registration No. 46,627
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FEB 17 2005

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

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INVENTOR(S) : James Kenneth Aragones et al.

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MAILING ADDRESS OF SENDER:

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SYSTEM AND METHOD FOR PREDICTING THE TIMING OF FUTURE SERVICE EVENTS OF A PRODUCT

BACKGROUND OF THE INVENTION

This disclosure relates generally to servicing products and systems and more particularly to predicting the timing of future service events of a product or a system.

The market for long-term contractual agreements has grown at high rates over recent years for many of today's service organizations. As the service organizations establish long-term contractual agreements with their customers, it becomes important to understand the expected costs and risks associated with the pricing of service contracts and portfolio management of the contracts. In addition, the service organizations need to have an understanding of the planning of repairs (shop workload planning) and how the introduction of new technology will affect their service contracts. In order to analyze these issues, it is necessary to correctly model the underlying behavior of the product or system so that each can be serviced in the most cost-effective manner.

Currently available analytical practices are unable to accurately model service requirements for complex products or systems. Typically, these models contain poor cost information which result in the service organization inefficiently managing the risk associated with their service portfolios, failing to respond to customer needs and new technology, which all lead to lower long-term contract profitability. A standard time-series method is one particular approach that has been used to model the service requirements of repairable systems such as aircraft engines, automobiles, locomotives and other high tech products. This time-series method examines historical data obtained over a five to ten year period and forms a trend line on either system costs and/or number of repairs made to the system. The trend line is then used to predict future costs and number of repairs. A limitation with this time series method is that it does not give details of failures at a compartmental level. A compartment is a physical or performance related sub-system of the repairable

product, which when it fails causes the product to require maintenance or servicing. Other limitations with the standard time series method is that it does not account for the life cycle of the repairable product and thus does not provide a distribution of the expected service events for the product. An analysis based on engineering relationships to determine compartment parameters is another method used to model the service requirements of repairable systems. A limitation with this analysis is that it is not well based in underlying statistics, and thus cannot be shown to accurately model the repairable product on an ongoing basis.

In order to overcome the above problems, there is a need for an approach that can model the service requirements of repairable systems that is accurate and has a comprehensive statistical framework. Such an approach will lead to better cost projections, more realistic and effective risk management, new technology introduction and day-to-day service that is more responsive to customer needs and higher long-term contract profitability.

BRIEF SUMMARY OF THE INVENTION

In accordance with one embodiment of this disclosure, there is a system for predicting the timing of a future service event of a product formed from a plurality of compartments. The system comprises a database that contains a plurality of service information and a plurality of performance information for the product. A statistical analyzer analyzes the plurality of service information to determine a plurality of compartment failure information. A performance deterioration rate analyzer analyzes the performance deterioration rate of the product from the plurality of service information and performance information. A simulator, simulates a distribution of future service events of the product according to the plurality of compartment failure information and the performance deterioration rate analysis.

Similarly, in this disclosure there is a method for predicting the timing of a future service event of a product formed from a plurality of compartments. The method comprises storing a plurality of service information and a plurality of performance information for the product; analyzing the plurality of service information to determine a plurality of compartment failure information; performing a deterioration rate analysis of the product from the plurality of service information and

performance information; and simulating a distribution of future service events of the product according to the plurality of compartment failure information and the deterioration rate analysis.

Also, in this disclosure there is a computer-readable medium storing computer instructions for instructing a computer to predict the timing of a future service event of a product formed from a plurality of compartments. The computer instructions comprise storing a plurality of service information and a plurality of performance information for the product; analyzing the plurality of service information to determine a plurality of compartment failure information; performing a deterioration rate analysis of the product from the plurality of service information and performance information and simulating a distribution of future service events of the product according to the plurality of compartment failure information and the deterioration rate analysis.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a schematic of a general purpose computer system in which a system for predicting the timing of future service events of a product operates;

Fig. 2 shows a schematic diagram of a system for predicting the timing of future service events of a product that operates on the computer system shown in Fig. 1;

Fig. 3 shows a flow chart describing actions performed by the system shown in Fig. 2;

Fig. 4 shows a flow chart describing the actions performed by the statistical analyzer shown in Fig. 2;

Fig. 5 shows a flow chart describing the actions performed by the performance deterioration rate analyzer shown in Fig. 2;

Figs. 6a-6b show examples of plots that describe some of the performance information stored in the performance historical database shown in Fig. 2;

Fig. 7 shows a flow chart describing the actions performed by the simulator shown in Fig. 2; and

Fig. 8 shows a flow diagram describing the validating actions performed by the system shown in Fig. 2.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows a schematic of a general-purpose computer system 10 in which a system for predicting the timing of future service events of a product operates. The computer system 10 generally comprises a processor 12, a memory 14, input/output devices, and data pathways (e.g., buses) 16 connecting the processor, memory and input/output devices. The processor 12 accepts instructions and data from the memory 14 and performs various calculations. The processor 12 includes an arithmetic logic unit (ALU) that performs arithmetic and logical operations and a control unit that extracts instructions from memory 14 and decodes and executes them, calling on the ALU when necessary. The memory 14 generally includes a random-access memory (RAM) and a read-only memory (ROM), however, there may be other types of memory such as programmable read-only memory (PROM), erasable programmable read-only memory (EPROM) and electrically erasable programmable read-only memory (EEPROM). Also, the memory 14 preferably contains an operating system, which executes on the processor 12. The operating system performs basic tasks that include recognizing input, sending output to output devices, keeping track of files and directories and controlling various peripheral devices.

The input/output devices comprise a keyboard 18 and a mouse 20 that enter data and instructions into the computer system 10. A display 22 allows a user to see what the computer has accomplished. Other output devices could include a printer, plotter, synthesizer and speakers. A modem or network card 24 enables the computer system 10 to access other computers and resources on a network. A mass

storage device 26 allows the computer system 10 to permanently retain large amounts of data. The mass storage device may include all types of disk drives such as floppy disks, hard disks and optical disks, as well as tape drives that can read and write data onto a tape that could include digital audio tapes (DAT), digital linear tapes (DLT), or other magnetically coded media. The above-described computer system 10 can take the form of a hand-held digital computer, personal digital assistant computer, personal computer, workstation, mini-computer, mainframe computer and supercomputer.

Fig. 2 shows a schematic diagram of a system 28 for predicting the timing of future service events of a product that operates on the computer system 10 shown in Fig. 1. In the system 28, a service database 30 stores a plurality of service information for the product. The plurality of service information varies depending on the product. Generally, the plurality of service information will comprise information such as compartment definitions of the product (i.e., a physical or performance related subsystem that is considered as a unit, which when it fails requires that the product needs maintenance or servicing), repair history of the product (e.g., dates of service events, types of service events, time for a compartment to fail, etc.), as well as any factors which may play a role in explaining the length of time which passes between service events (e.g., environment, operating conditions of the product, product configuration, equipment age, etc.). Other factors may include types of maintenance, cycle time of the product, usage of the product, contract terms and conditions, equipment age and vintage, etc. In this disclosure, the product will be described with reference to an aircraft engine; however, other products such as a power system, a locomotive or any other electrical, chemical or mechanical products, where it is desirable to predict the timing of future service events, may be used.

Referring to Fig. 2, a preprocessor 32 processes the plurality of service information into a predetermined format. The preprocessing includes extracting the plurality of service information from the service database 30; assigning each data record in the database to a compartment depending upon the engineering labeled removal cause; creating new variables from existing variables (e.g., censoring variables, customer indicator variables), deleting outliers and producing summary

statistics of the data set (e.g., number of records for each compartment). After performing these acts, the preprocessor 32 generates a plurality of data files according to the service information, wherein each of these data files are formatted as SAS data sets.

A statistical analyzer 34 analyzes the plurality of processed service information to determine a plurality of compartment failure information. The compartment failure information may include statistically significant compartment failure variables and the associated compartment time-to-failure coefficients. Compartment failure variables are variables that affect the time between service or maintenance events. For example, in the aircraft engine scenario, the thrust rating of the engine and the environment that the engine flies in are examples of possible statistically significant compartment failure variables. Compartment time-to-failure coefficients are coefficients that are applied to each of the compartment failure variables. The compartment failure variables and associated compartment time-to-failure coefficients are used to determine the time between servicing events for the compartments. In addition, the statistical analyzer 34 uses this information to determine which compartment failure variables influence service events and estimate time-to-failure distributions for the compartments.

The statistical analyzer 34 comprises several scripts that enable it to perform the aforementioned functions as well as some additional functions. One particular script that the statistical analyzer 34 uses is a service analysis script that executes a plurality of statistical procedures. The plurality of statistical procedures may comprise a multi-variate regression and/or a correlation analysis. Both the multi-variate regression and correlation can determine which compartment failure variables influence the timing of service events and estimate the time-to-failure distributions for the compartments. The statistical analyzer 34 uses other scripts to output this information as well as statistical diagnostics 36 and residual plots 38. The output from the multi-variate regression and/or correlation analysis may include the compartment time-to-failure coefficients for each compartment associated with the product. Other standard output from the multi-variate regression and/or correlation

analysis may include a standard error associated with each of the compartment time-to-failure coefficients and a P value, which is an indication of whether a particular variable has a significant effect on the time between occurrences of service events.

Statistical diagnostics that may be outputted include goodness-of-fit metrics and collinearity diagnostics. These enable a user to determine the most appropriate compartment model in the statistical analyzer 34. Residual plots enable a user of the system 28 to determine how well the regression model fits the service information data. Generally, the residual plots are defined as the difference between the actual time until servicing values and the predicted time until servicing values. A small residual value is an indication that the regression or correlation analysis was a good fit, whereas a large residual value is an indication that the fit may be improved.

In addition to residual plots, the statistical analyzer 34 may use another script to output information such as probability plots, which enables one to assess whether the assumed life distribution for each compartment is appropriate or not. Another script may be used to generate a plot of residuals versus each variable that affects the time that a service event occurs.

Referring again to Fig. 2, the system 28 also comprises a performance historical database 40 that includes a plurality of performance information obtained from the product while in operation. As mentioned above, this disclosure is described with reference to an aircraft engine. Therefore, the performance information can be acquired by using any of a plurality of data acquisition devices such as sensors and transducers. After the data have been obtained, the data acquisition devices can transfer the data to a remote monitoring facility for storage and evaluation. Also, it is possible to have the data from the data acquisition devices manually recorded and entered into the performance historical database 40. The plurality of performance information includes but is not limited to information such as performance characteristic values (e.g., exhaust gas temperature, EGT), initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of a subset of compartments of the product. For this aircraft

engine embodiment, the variables may include flight leg, engine thrust, customer, engine model, engine series, etc. All of this performance information is described below in more detail.

A performance deterioration rate analyzer 42 analyzes the performance characteristic values of the product from both the plurality of service information and performance information. The performance deterioration rate analyzer 42 comprises a statistical analysis script that relates a subset of compartments of the product according to time. For purposes of describing the performance deterioration rate analyzer 42, time is the amount of time that the aircraft engine is in use. Time can be measured by variables such as cycles or hours. The statistical analysis script generates an estimated deterioration rate curve for a subset of compartments of the product. The performance deterioration rate analyzer 42 further comprises a transformer that transforms each estimated deterioration rate curve for a compartment to a performance life distribution. A performance life distribution is a statistical distribution representing the statistical properties of the time between servicing events and is estimated using performance data as opposed to service data. The performance life distribution is in the same form as the estimated time-to-failure distributions for the compartments determined by the statistical analyzer 34.

A simulator 44 simulates the future service events of the product according to the plurality of compartment failure information generated by the statistical analyzer 34 and the performance life distribution generated by the performance deterioration rate analyzer 42. The simulation results in a forecast of the timing of the future service events. In particular, the simulator 44 takes the compartment time-to-failure coefficients from the statistical analyzer 34 and determines a Weibull distribution for each compartment defined for the product. Also, the simulator 44 takes the performance life distribution from the performance deterioration rate analyzer 42 and determines a Weibull distribution for each of the associated compartments defined for the product. The simulator 44 then uses the compartment distributions to determine the overall distribution for the product. Generally, the simulator uses a discrete event-driven Monte Carlo simulation to

perform the above operations. After performing the simulation, the simulator 44 generates several outputs. For instance, one output is the contract output 46, which typically comprises the following: maintenance event distribution parameters over time; demand distributions spare/leased equipment; and equipment performance distributions (e.g., aircraft engine time on wing). The simulator 44 is not limited to these outputs and it is possible to use other outputs if desired.

In order to understand the performance of the simulator 44, the system 28 uses a validator, which can be part of the statistical analyzer 34 or the simulator or separate from both. The validator contains a validation script prepared for a case study done for the product. For purposes of this disclosure, a case study is defined as any subset of historical service event data that is used for model validation. For example, the service events that took place on a group of randomly chosen systems over the past year may serve as a case study, and during validation, a comparison is made between the number of service events projected by the model for these systems over this period of time and the actual number of service events that took place. The validation script will compare the compartment distributions determined by the simulator 44 to the distributions that actually happened in the case study. After making the comparison, the validator generates a series of graphical outputs 48 on availability and reliability. In a preferred embodiment, three sets of reliability graphs are generated. The first set of reliability graphs are relative frequency histograms of the actual compartment distributions for each of the first four shop visits for the case study. Overlaid on these relative frequency histograms are the compartment distributions determined by the simulator 44. The second set of reliability graphs are relative frequency histograms of the actual system level distributions for each of the first four shop visits for the case study. Overlaid on each of these relative frequency histograms are the system distributions determined by the simulator 44. The third set of reliability graphs are non-parametric Kaplan-Meier estimated survival curves determined from both the actual system level distribution and the system level distribution determined by the simulator 44 for each of the first four shop visits. From these outputs, a user can generate a service plan forecast for the product that comprises time for scheduling service events.

Fig. 3 shows a flow chart describing actions performed by the system 28 shown in Fig. 2. At block 50, a plurality of service information and performance information for the product stored in the service database and the performance historical database, respectively, are obtained. The preprocessor preprocesses the plurality of service information into a predetermined format at 52. The statistical analyzer analyzes the plurality of processed service information to determine a plurality of compartment failure information at 54. In particular, the statistical analyzer determines both the compartment time-to-failure coefficients and the compartment failure variables using the aforementioned statistical procedures. The statistical analyzer outputs the compartment time-to-failure coefficients and the compartment failure variables to the simulator and generates various residual plots.

At the same time the service information are being preprocessed and analyzed by the preprocessor and the statistical analyzer, the performance information are simultaneously evaluated by the performance deterioration rate analyzer. If desired, it is also possible to have the performance information preprocessed in a manner similar to the service information. Regardless of whether the performance information are preprocessed, the performance deterioration rate analyzer runs a deterioration rate analysis at 56. As mentioned above, the deterioration rate analysis generates an estimated deterioration rate curve for a subset of compartments of the product and transforms each estimated deterioration rate curve to a performance life distribution.

After analyzing the service information and the performance information, the simulator simulates the future service events of the product according to the compartment failure information and the performance life distribution at 58. In addition, the simulator forecasts or predicts the timing of the future service events at 60. As mentioned above, this information is in the form of distributions for each compartment that makes up the product. The validator compares the compartment distributions determined by the simulator to the distributions that actually happened in the case study at 62. After making the comparison, the validator generates a series of graphical outputs on availability and reliability.

Fig. 4 shows a flow chart describing the actions performed by the statistical analyzer shown in Fig. 2. At block 64, the statistical analyzer obtains the service information from the preprocessor. The statistical analyzer then generates compartment definitions for the service information at 66. At 68, the statistical analyzer determines compartment failure information such as the statistically significant compartment failure variables and their associated compartment time-to-failure coefficients using the aforementioned statistical procedures. The statistical analyzer then applies the compartment time-to-failure coefficients to the compartment failure variables at 70. At block 72, the statistical analyzer generates the various statistical diagnostics for each compartment associated with the product. At block 74, the statistical analyzer generates residual plots and probability plots and other types of plots if desired. As mentioned above, the statistical analyzer can generate other information such as standard errors associated with each of the compartment time-to-failure coefficients and a *P* value.

Fig. 5 shows a flow chart describing the actions performed by the performance deterioration rate analyzer 42 shown in Fig. 2. Before running the deterioration rate analysis, the performance deterioration rate analyzer first obtains the plurality of service information and performance information from the service database and the performance historical database, respectively, at 76. As mentioned earlier, the plurality of performance information includes information such as performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of each compartment of the product.

Figs. 6a-6b show examples describing some of the above-mentioned performance information. In particular, Fig. 6a shows an example of a deterioration rate curve for a compartment of an aircraft engine. In this example, the compartment is EGT, however, other compartments could be used. For instance, an illustrative but non-exhaustive list could include delta exhaust gas temperature (dEGT), which is the deviation from the baseline EGT, fuel flow (WF), core speed (N2), and EGT divergence, divEGT, which is the difference of the EGT between the raw EGT of the

engine in question and the mean of raw EGT of all engines. The deterioration curve shows the degradation of the compartment over time. Eventually, after a period of time, the compartment reaches a level that the degradation is severe enough to warrant servicing. The initial data level performance parameter is the initial level of the compartment after being serviced. In Fig. 6a, the initial level is about 50°F, and over time the level of the EGT margin will degrade. The historical trending levels are shown in Fig. 6a as data points. Fig. 6b shows an example of the raw EGT levels. In particular, Fig. 6b shows a plot illustrating the removal level or redline for the EGT compartment. The removal level indicates an absolute time that the compartment reaches a predetermined level that necessitates the removal of the aircraft engine for servicing.

Referring back to Fig. 5, after the service information and the performance information are obtained, the performance deterioration rate analyzer executes the statistical analysis script that relates each compartment of the product according to time at 78. Preferably, the statistical analysis runs a multi-variate regression analysis for each compartment of the product to identify variables that influence the time between servicing events. An illustrative example of a multi-variate regression analysis using a Weibull distribution is presented. The time (specified either in engine flight hours or engine cycles) between service events is represented as Y. As mentioned earlier, thrust (X1) and flight leg (X2) are two compartment failure variables that might influence the time between service events, Y. The multi-variate Weibull regression model takes the form:

$$\ln(Y) = \alpha + \beta_1 X1 + \beta_2 X2 + \sigma\varepsilon,$$

where ln is the natural log function, ε is an error term which follows the smallest extreme value distribution, and α, β_1, β_2, and σ are compartment failure parameters to be estimated from the service data.

For fixed values of thrust (X1) and flight leg (X2), a Weibull distribution representing time between servicing events may be determined. For

example, if α=8.9, β_1=-0.00003, β_2=0.75, and σ=0.5 where X1=23500 and X2=1.8, the Weibull distribution of the time between servicing events for this compartment would have a location (or scale) parameter (i.e., the 63.2nd failure percentile) of exp(8.9-0.00003*23500+0.75*1.8)=13975 and a shape parameter equal to $1/\sigma$=1/0.50=2.0. Although a Weibull regression analysis is described, other statistical analyses such as multiple non-linear and loglinear analyses could also be used.

The performance deterioration rate analyzer generates estimated deterioration rate curves for a subset of compartments of the product at 80. The estimated deterioration rate curves are determined using a multi-variate regression and/or correlation statistical analysis. Denote the performance characteristic (e.g., EGT margin) as Y. One example of a multi-variate regression and/or correlation analysis is presented using Y and time (as measured in cycles) in the following model:

$$Y = \alpha + \beta_1 Cycles + \varepsilon$$

where ε follows a normal distribution and α and β_1 are parameters to be estimated from the performance and service information data. The estimate of β_1 in this example is an estimated rate of deterioration for the performance characteristic, Y. For example, if β_1= 0.003 then the performance characteristic, Y, deteriorates at approximately 3 degrees per 1000 cycles.

Next, the performance deterioration rate analyzer transforms each estimated deterioration rate curve for the respective compartment to a performance life distribution at 82. The performance life distribution is characterized by a location (or scale) parameter and a shape parameter. In order to perform the transformation, estimates of α, β_1, and a performance characteristic limit value (i.e., a value at which the compartment requires servicing) which we denote by EGTL, are required. The location (or scale) parameter of the performance life distribution is obtained using the following formula:

$$Location = \exp\left(\frac{\ln\left(\frac{EGTL-\alpha}{\beta_1}\right) * \ln(-\ln(1-0.825)) - \ln\left(\frac{EGTL-\alpha}{\beta_1 - \beta_1/3}\right) * \ln(-\ln(1-0.50))}{\ln(-\ln(1-0.825)) - \ln(-\ln(1-0.5))}\right)$$

The shape parameter of the performance life distribution is obtained using the following formula:

$$Shape = \frac{\ln(-\ln(1-0.825))}{\ln\left(\frac{EGTL-\alpha}{\beta_1 - \beta_1/3}\right) - \ln(Location)}.$$

As an example, suppose the estimate of α is 0, the estimate of β_1=0.003 and the performance characteristic value is 60. Using the formula above, the location parameter value is estimated to be 23498. The shape parameter is estimated to be 2.27. The performance life distributions for all compartments are then transferred to the simulator at 84.

Fig. 7 shows a flow chart describing the actions performed by the simulator 44 shown in Fig. 2. As mentioned earlier, the simulator 44 is interested in determining the distribution of failures at the product's system level so that the timeliness of future service events can be predicted. The simulator 44 is able to determine the distribution of failures at the product's system level because of the information provided by the statistical analyzer 34 and the performance deterioration rate analyzer 42. The information (i.e., time-to-failure coefficients and compartment variables) provided by the statistical analyzer 34 facilitates an understanding of each of the compartments that make up the product's system level and their relationship with each other, while the performance life distributions provided by the performance deterioration rate analyzer gives more information about probable service requirements. The simulator 44 uses this information to examine the system or aggregate level and predict the overall timing of service events for the product. Referring back to Fig. 7, the actions performed by the simulator begin at block 86,

where random failure times (i.e., service events) for each compartment distribution are generated. From the randomly generated failure times, the minimum of these values is found at 88. The simulator designates t_i as the minimum time, where i is the compartment associated with this time value. The simulator then records the minimum time t_i as the next failure time (i.e., time for a service event) for the system level at 90. At 92, the simulator determines whether there are any more system level failures needed. If so, then blocks 86-90 are repeated a large number of times. Once all of the iterations have been performed, the simulator forms a system level distribution from the failure times at 94. At 96, the simulator generates the output tables and the input report, while a graphical output is generated at 98.

Fig. 8 shows a flow diagram describing the validating actions performed by the system shown in Fig. 1. In this diagram, historical service event data and the performance historical data are stored in a database at 100. After identifying a case study, the historical service event data and performance historical data are separated out according to the case study at 102. If the historical service event data and performance historical data are not in the case study, then this data are used to build a model as described in Fig. 2 at 104. Project service incidents along with statistical confidence bounds that should take place in the case study are determined at 106. An example of the project service incidents along with statistical confidence bounds are shown at 108. The service incidents are compared to data that are used in the case study at 110. If the actual data do not match the projection, then the model needs to be reexamined as noted at 112. On the other hand, if the data do match the projection within the statistical confidence bounds, then the model is validated as noted at 114.

The foregoing flow charts of this disclosure show the architecture, functionality, and operation of a possible implementation of the system for predicting the timing of future service events of a product. In this regard, each block represents a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that in some alternative implementations, the functions noted in the blocks may occur

out of the order noted in the figures, or for example, may in fact be executed substantially concurrently or in the reverse order, depending upon the functionality involved.

The above-described system and method for predicting the timing of future service events of a product comprise an ordered listing of executable instructions for implementing logical functions. The ordered listing can be embodied in any computer-readable medium for use by or in connection with a computer-based system that can retrieve the instructions and execute them. In the context of this application, the computer-readable medium can be any means that can contain, store, communicate, propagate, transmit or transport the instructions. The computer readable medium can be, for example but not limited to, an electronic, magnetic, optical, electromagnetic, infrared system, apparatus, or device. An illustrative, but non-exhaustive list of computer-readable mediums can include an electrical connection (electronic) having one or more wires, a portable computer diskette (magnetic), a random access memory (RAM) (magnetic), a read-only memory (ROM) (magnetic), an erasable programmable read-only memory (EPROM or Flash memory) (magnetic), an optical fiber (optical), and a portable compact disc read-only memory (CDROM) (optical). It is even possible to use paper or another suitable medium upon which the instructions are printed. For instance, the instructions can be electronically captured via optical scanning of the paper or other medium, then compiled, interpreted or otherwise processed in a suitable manner if necessary, and then stored in a computer memory.

It is apparent that there has been provided in accordance with this invention, a system and method for predicting the timing of future service events of a product. While the invention has been particularly shown and described in conjunction with a preferred embodiment thereof, it will be appreciated that variations and modifications can be effected by a person of ordinary skill in the art without departing from the scope of the invention.

WHAT IS CLAIMED IS:

1. A system for predicting the timing of a future service event of a product formed from a plurality of compartments, comprising:

a database that contains a plurality of service information and a plurality of performance information for the product;

a statistical analyzer that analyzes the plurality of service information to determine a plurality of compartment failure information;

a performance deterioration rate analyzer that analyzes performance deterioration rate of the product from the plurality of service information and performance information; and

a simulator for simulating a distribution of future service events of the product according to the plurality of compartment failure information and the performance deterioration rate analysis.

2. The system according to claim 1, wherein the database comprises a service database and a performance historical database.

3. The system according to claim 1, wherein the plurality of service information comprises compartment definitions, repair history and service factors.

4. The system according to claim 1, wherein the plurality of performance information comprises performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of a subset of the plurality of compartments.

5. The system according to claim 1, further comprising a preprocessor for processing the plurality of service information into a predetermined format.

6. The system according to claim 1, wherein the preprocessor generates a plurality of data files according to the plurality of service information.

7. The system according to claim 1, wherein the plurality of compartment failure information comprises compartment failure variables and compartment time-to-failure coefficients.

8. The system according to claim 7, wherein the statistical analyzer uses the plurality of compartment failure information to determine which compartment failure variables influence the timing of future service events and estimate time-to-failure distributions for the plurality of compartments.

9. The system according to claim 8, wherein the statistical analyzer uses the estimated time-to-failure distributions to determine a Weibull distribution for a subset of the plurality of compartments defined for the product.

10. The system according to claim 1, wherein the statistical analyzer comprises a service analysis script that executes a plurality of statistical procedures.

11. The system according to claim 10, wherein the plurality of statistical procedures comprise a multivariate regression and/or a correlation analysis.

12. The system according to claim 10, wherein the service analysis script generates a plurality of statistical diagnostic information.

13. The system according to claim 12, wherein the plurality of statistical diagnostic information comprises goodness-of-fit metrics and collinearity diagnostics.

14. The system according to claim 10, wherein the service analysis script generates a plurality of residual plots.

15. The system according to claim 1, wherein the statistical analyzer comprises a validation script.

16. The system according to claim 15, wherein the validation script is applied to a plurality of case studies set up for the product.

17. The system according to claim 1, wherein the performance deterioration rate analyzer comprises a statistical analysis script that relates a subset of compartments of the product according to time.

18. The system according to claim 17, wherein the statistical analysis script generates an estimated deterioration rate curve for the subset of compartments of the product.

19. The system according to claim 18, wherein the performance deterioration rate analyzer further comprises a transformer that transforms each estimated deterioration rate curve for a compartment to a performance life distribution.

20. The system according to claim 19, wherein the simulator uses the performance life distributions to determine a Weibull distribution for a subset of the plurality of compartments defined for the product.

21. The system according to claim 1, wherein the simulator forecasts a service plan for the future service events that comprises the time for scheduling the service events.

22. A system for predicting the timing of a future service event of a product formed from a plurality of compartments, comprising:

means for containing a plurality of service information and a plurality of performance information for the product;

means for analyzing the plurality of service information to determine a plurality of compartment failure information;

means for performing a deterioration rate analysis that determines performance deterioration rate of the product from the plurality of service information and performance information; and

means for simulating a distribution of future service events of the product according to the plurality of compartment failure information and the performance deterioration rate analysis.

23. The system according to claim 22, wherein the plurality of service information comprises compartment definitions, repair history and service factors.

24. The system according to claim 22, wherein the plurality of performance information comprises performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of a subset of the plurality of compartments of the product.

25. The system according to claim 22, further comprising means for preprocessing the plurality of service information into a predetermined format.

26. The system according to claim 25, wherein the preprocessing means generates a plurality of data files according to the plurality of service information.

27. The system according to claim 22, wherein the plurality of compartment failure information comprises compartment failure variables and compartment time-to-failure coefficients.

28. The system according to claim 27, wherein the analyzing means uses the plurality of compartment failure information to determine which compartment failure variables influence the timing of future service events and estimate time-to-failure distributions for the compartments.

29. The system according to claim 28, wherein the analyzing means uses the estimated time-to-failure distributions to determine a Weibull distribution for a subset of the plurality of compartments defined for the product.

30. The system according to claim 22, wherein the analyzing means comprises a service analysis script that executes a plurality of statistical procedures.

31. The system according to claim 30, wherein the plurality of statistical procedures comprise a multivariate regression and/or a correlation analysis.

32. The systemaccording to claim 30, wherein the service analysis script generates a plurality of statistical diagnostic information.

33. The system according to claim 32, wherein the plurality of statistical diagnostic information comprises goodness-of-fit metrics and collinearity diagnostics.

34. The system according to claim 30, wherein the service analysis script generates a plurality of residual plots.

35. The system according to claim 22, wherein the analyzing means comprises a validation script.

36. The system according to claim 35, wherein the validation script is applied to a plurality of case studies set up for the product.

37. The system according to claim 22, wherein the performing means comprises a statistical analysis script that relates a subset of the plurality of compartments of the product according to time.

38. The system according to claim 37, wherein the statistical analysis script generates an estimated deterioration rate curve for a subset of the plurality of compartments of the product.

39. The system according to claim 38, wherein the performing means further comprises means for transforming each estimated deterioration rate curve for a compartment to a performance life distribution.

40. The system according to claim 39, wherein the simulator uses the performance life distribution to determine a Weibull distribution for a subset of the plurality of compartments defined for the product.

41. The system according to claim 22, wherein the simulator forecasts a service plan for the future service events that comprises the time for scheduling the service events.

42. A method for predicting the timing of a future service event of a product formed from a plurality of compartments, comprising;

storing a plurality of service information and a plurality of performance information for the product;

analyzing the plurality of service information to determine a plurality of compartment failure information;

performing a deterioration rate analysis of the product from the plurality of service information and performance information; and

simulating a distribution of future service events of the product according to the plurality of compartment failure information and the deterioration rate analysis.

43. The method according to claim 42, wherein the plurality of service information comprises compartment definitions, repair history and service factors.

44. The method according to claim 42, wherein the plurality of performance information comprises performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of a subset of the plurality of compartments of the product.

45. The method according to claim 42, further comprising preprocessing the plurality of service information into a predetermined format.

46. The method according to claim 45, wherein the preprocessing generates a plurality of data files according to the plurality of service information.

47. The method according to claim 42, wherein the plurality of compartment failure information comprises compartment failure variables and compartment time-to-failure coefficients.

48. The method according to claim 47, wherein the analyzing uses the plurality of compartment failure information to determine which compartment failure variables influence the timing of future service events and estimate time-to-failure distributions for the plurality of compartments.

49. The method according to claim 48, wherein the analyzing uses the estimated time-to-failure distributions to determine a Weibull distribution for a subset of the plurality of compartments.

50. The method according to claim 42, wherein the analyzing comprises using a service analysis script that executes a plurality of statistical procedures.

51. The method according to claim 50, wherein the plurality of statistical procedures comprise a multivariate regression and/or a correlation analysis.

52. The method according to claim 51, wherein the service analysis script generates a plurality of statistical diagnostic information.

53. The method according to claim 52, wherein the plurality of statistical diagnostic information comprises goodness-of-fit metrics and collinearity diagnostics.

54. The method according to claim 50, wherein the service analysis script generates a plurality of residual plots.

55. The method according to claim 42, wherein the analyzing comprises using a validation script.

56. The method according to claim 55, wherein the validation script is applied to a plurality of case studies set up for the product.

57. The method according to claim 42, wherein the performing comprises using a statistical analysis script that relates a subset of the plurality of compartments of the product according to time.

58. The method according to claim 57, wherein the statistical analysis script generates an estimated deterioration rate curve for a subset of the plurality of compartments of the product.

59. The method according to claim 58, wherein the performing a deterioration rate analysis further comprises transforming each estimated deterioration rate curve for a compartment to a performance life distribution.

60. The method according to claim 59, wherein the simulating uses the performance life distributions to determine a Weibull distribution for a subset of the plurality of compartments.

61. The method according to claim 42, wherein the simulating forecasts a service plan for the future service events that comprises the time for scheduling the service events.

62. A computer-readable medium storing computer instructions for instructing a computer system to predict the timing of a future service event of a product formed from a plurality of compartments, the computer instructions comprising:

storing a plurality of service information and a plurality of performance information for the product;

analyzing the plurality of service information to determine a plurality of compartment failure information;

performing a deterioration rate analysis of the product from the plurality of service information and performance information; and

simulating a distribution of future service events of the product according to the plurality of compartment failure information and the deterioration rate analysis.

63. The computer-readable medium according to claim 62, wherein the plurality of service information comprises compartment definitions, repair history and service factors.

64. The computer-readable medium according to claim 62, wherein the plurality of performance information comprises performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of a subset of the plurality of compartments of the product.

65. The computer-readable medium according to claim 62, further comprising preprocessing instructions that preprocess the plurality of service information into a predetermined format.

66. The computer-readable medium according to claim 65, wherein the preprocessing instructions generates a plurality of data files according to the plurality of service information.

67. The computer-readable medium according to claim 62, wherein the plurality of compartment failure information comprises compartment failure variables and compartment time-to-failure coefficients.

68. The computer-readable medium according to claim 67, wherein the analyzing instructions uses the plurality of compartment failure information to determine which compartment failure variables influence the timing of future service events and estimate time-to-failure distributions for the plurality of compartments.

69. The computer-readable medium according to claim 68, wherein the analyzing instructions use the estimated time-to-failure distributions to determine a Weibull distribution for a subset of the plurality of compartments.

70. The computer-readable medium according to claim 62, wherein the analyzing instructions comprises instructions for using a service analysis script that executes a plurality of statistical procedures.

71. The computer-readable medium according to claim 70, wherein the plurality of statistical procedures comprise a multivariate regression and/or a correlation analysis.

72. The computer-readable medium according to claim 71, wherein the service analysis script generates a plurality of statistical diagnostic information.

73. The computer-readable medium according to claim 72, wherein the plurality of statistical diagnostic information comprises goodness-of-fit metrics and collinearity diagnostics.

74. The computer-readable medium according to claim 70, wherein the service analysis script generates a plurality of residual plots.

75. The computer-readable medium according to claim 62, wherein the analyzing instructions comprise using a validation script.

76. The computer-readable medium according to claim 75, wherein the validation script is applied to a plurality of case studies set up for the product.

77. The computer-readable medium according to claim 62, wherein the performing instructions comprise using a statistical analysis script that relates a subset of the plurality of compartments of the product according to time.

78. The computer-readable medium according to claim 77, wherein the statistical analysis script generates an estimated deterioration rate curve for a subset of the plurality of compartments of the product.

79. The computer-readable medium according to claim 78, wherein the performing instructions further comprise transforming instructions that transform each estimated deterioration rate curve to a performance life distribution.

80. The computer-readable medium according to claim 79, wherein the simulating instructions use the performance life distribution to determine a Weibull distribution for a subset of the plurality of compartments.

81. The computer-readable medium according to claim 62, wherein the simulating instructions forecasts a service plan for the future service events that comprises the time for scheduling the service events.

SYSTEM AND METHOD FOR PREDICTING THE TIMING OF FUTURE SERVICE EVENTS OF A PRODUCT

ABSTRACT OF THE DISCLOSURE

A system and method for predicting timing of future service events of a product. A database contains a plurality of service information and performance information for the prodúct. A statistical analyzer analyzes the plurality of processed service information to determine a plurality of compartment failure information. A performance deterioration rate analyzer analyzes the performance deterioration rate of the product from the plurality of service information and performance information. A simulator, simulates a distribution of future service events of the product according to the plurality of compartment failure information and the performance deterioration rate analysis.

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Aragones et al.

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(45) **Date of Patent: Sep. 28, 2004**

(54) **SYSTEM AND METHOD FOR PREDICTING THE TIMING OF FUTURE SERVICE EVENTS OF A PRODUCT**

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(73) Assignee: **General Electric Comapny**, Niskayuna, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/578,095**

(22) Filed: **May 25, 2000**

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(52) **U.S. Cl.** **703/22**; 703/7; 703/25; 703/13; 702/34

(58) **Field of Search** 703/7, 22, 13, 703/25; 701/10, 29, 19; 702/182, 34; 707/200; 705/3; 716/4

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Assistant Examiner—Kandasamy Thangavelu
(74) *Attorney, Agent, or Firm*—David C. Goldman; Patrick K. Patnode

(57) **ABSTRACT**

A system and method for predicting timing of future service events of a product. A database contains a plurality of service information and performance information for the product. A statistical analyzer analyzes the plurality of processed service information to determine a plurality of compartment failure information. A performance deterioration rate analyzer analyzes the performance deterioration rate of the product from the plurality of service information and performance information. A simulator, simulates a distribution of future service events of the product according to the plurality of compartment failure information and the performance deterioration rate analysis.

61 Claims, 9 Drawing Sheets

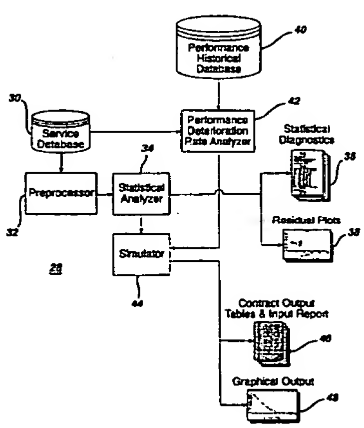

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FIG. 1

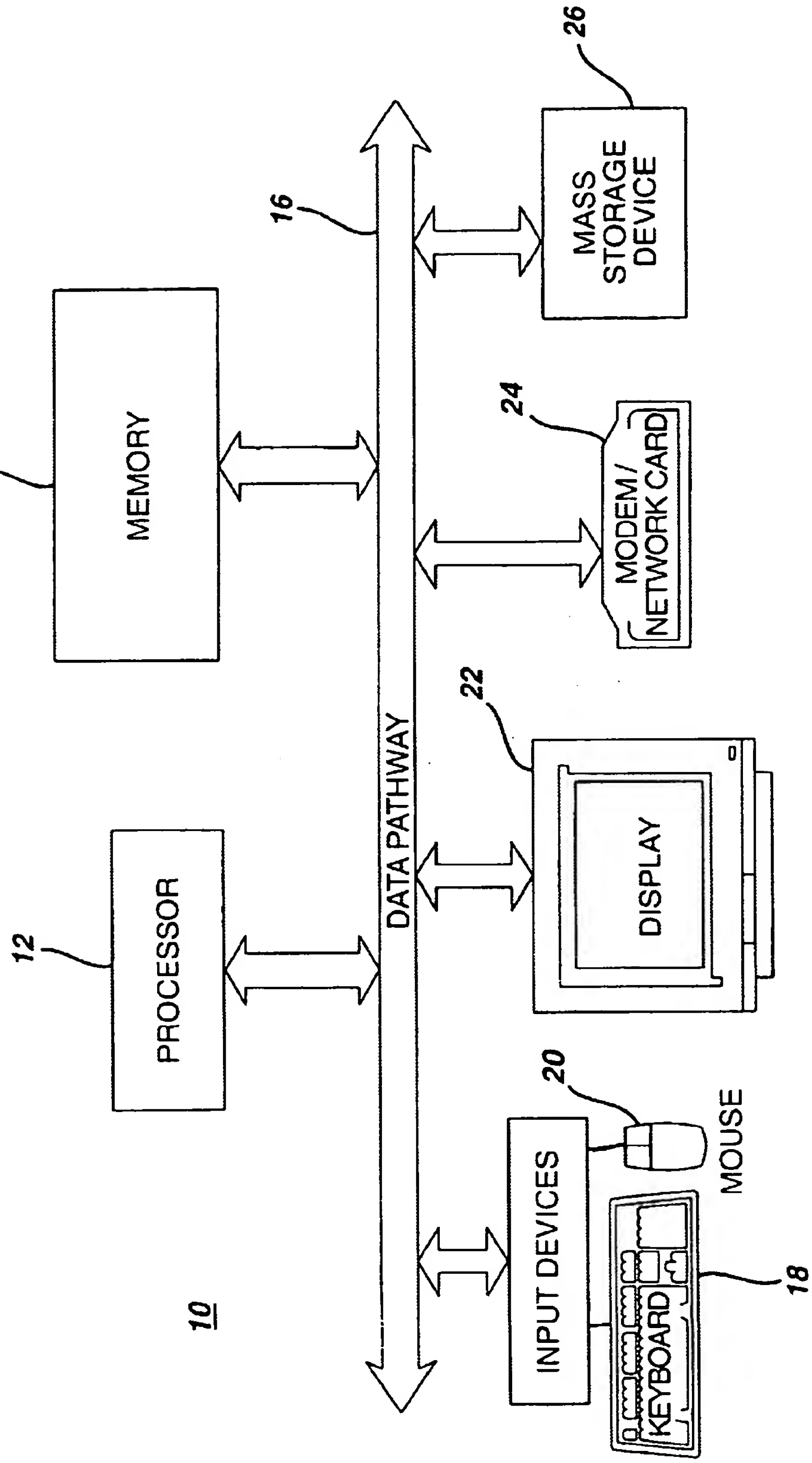

10
PROCESSOR
12
MEMORY
14
DATA PATHWAY
16
INPUT DEVICES
KEYBOARD
18
MOUSE
20
DISPLAY
22
MODEM / NETWORK CARD
24
MASS STORAGE DEVICE
26

FIG. 2

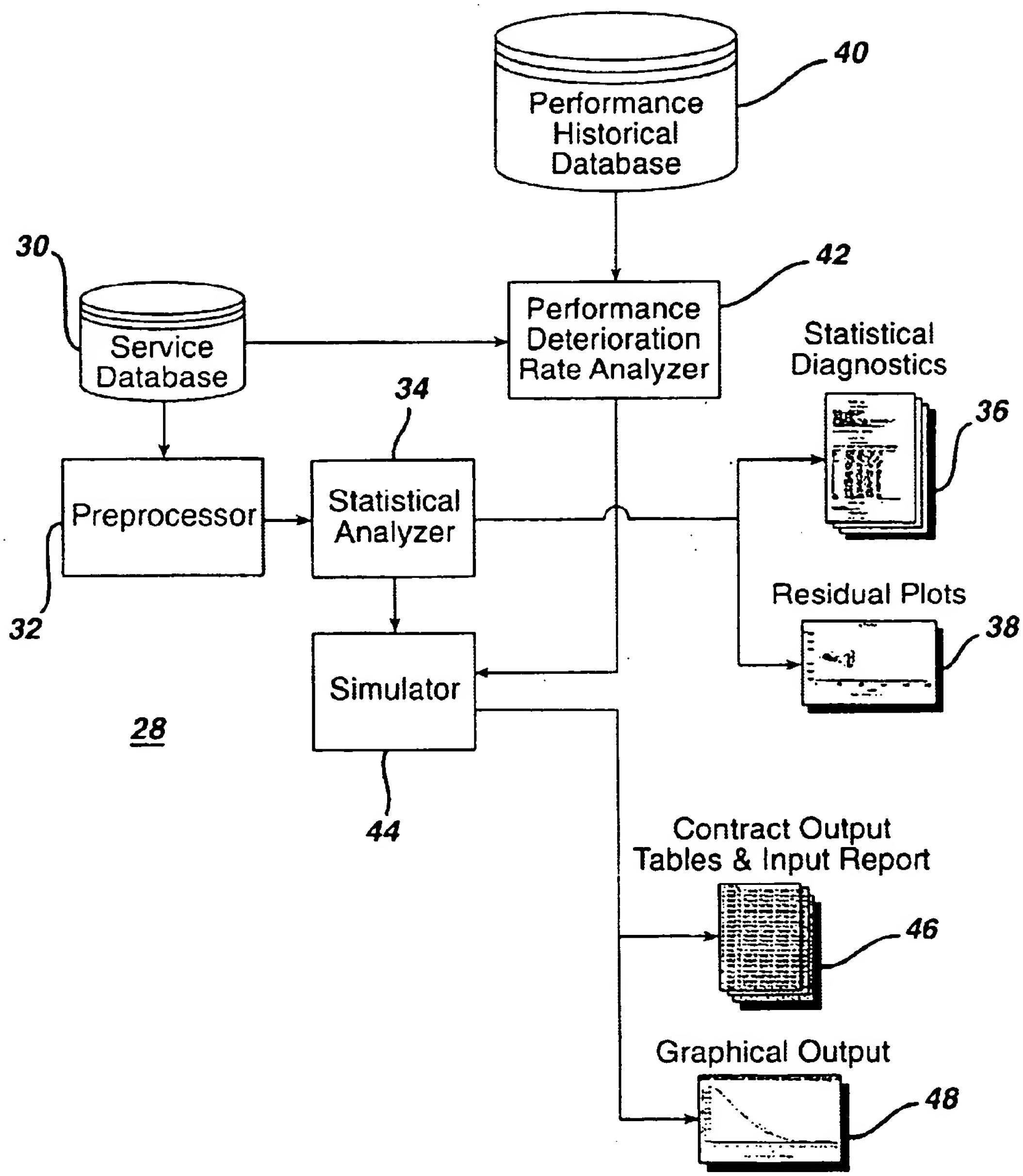

Performance Historical Database
40
30
Service Database
Performance Deterioration Rate Analyzer
42
Statistical Diagnostics
34
36
Preprocessor
Statistical Analyzer
32
Residual Plots
38
Simulator
28
44
Contract Output Tables & Input Report
46
Graphical Output
48

FIG. 3

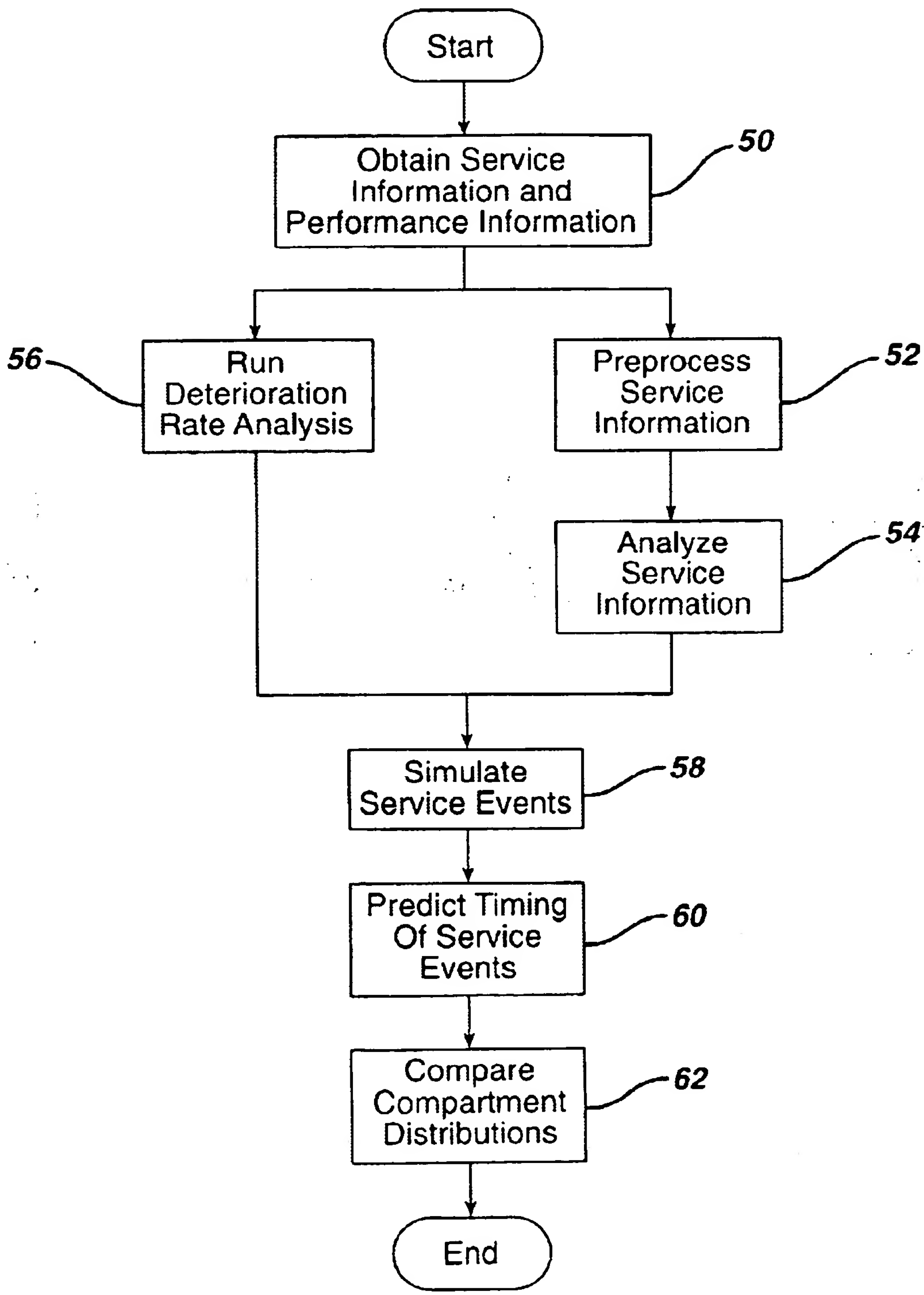

Start
Obtain Service Information and Performance Information
50
Run Deterioration Rate Analysis
56
Preprocess Service Information
52
Analyze Service Information
54
Simulate Service Events
58
Predict Timing Of Service Events
60
Compare Compartment Distributions
62
End

FIG. 4

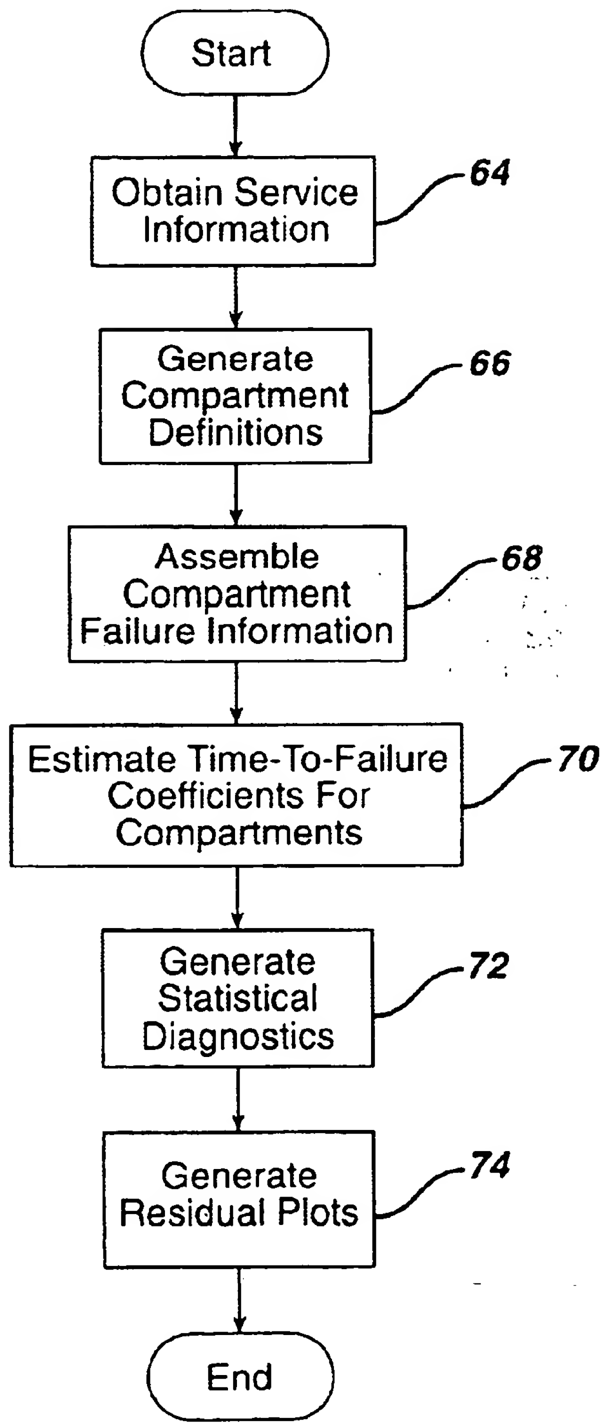

Start
Obtain Service Information
64
Generate Compartment Definitions
66
Assemble Compartment Failure Information
68
Estimate Time-To-Failure Coefficients For Compartments
70
Generate Statistical Diagnostics
72
Generate Residual Plots
74
End

FIG. 5

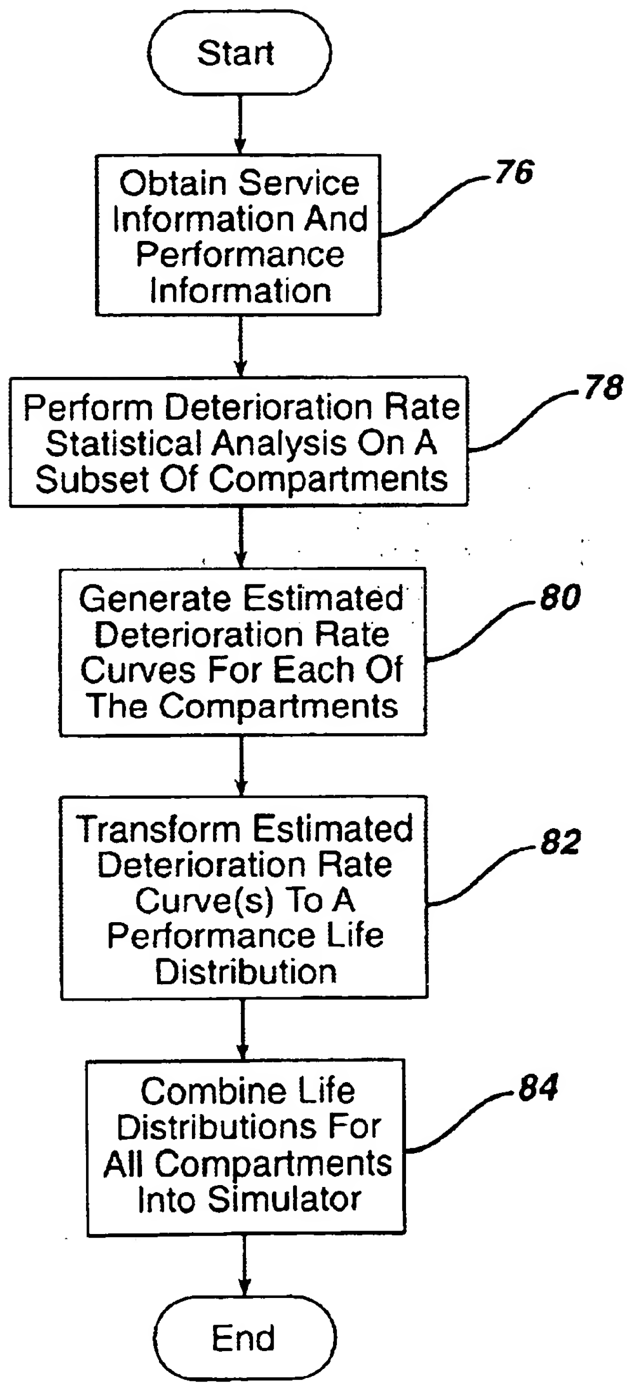

Start
Obtain Service Information And Performance Information
76
Perform Deterioration Rate Statistical Analysis On A Subset Of Compartments
78
Generate Estimated Deterioration Rate Curves For Each Of The Compartments
80
Transform Estimated Deterioration Rate Curve(s) To A Performance Life Distribution
82
Combine Life Distributions For All Compartments Into Simulator
84
End

FIG. 6a

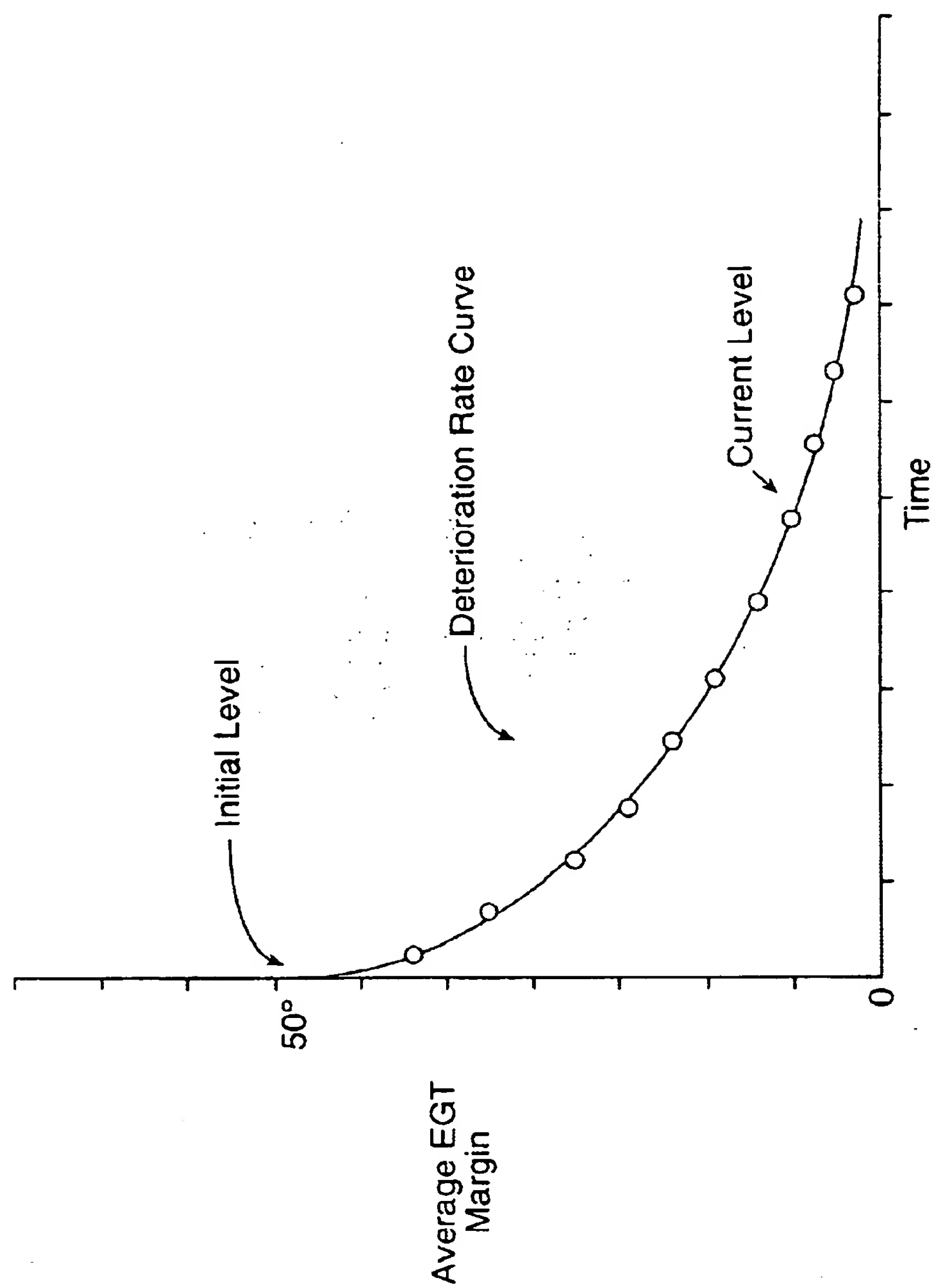

Initial Level
Deterioration Rate Curve
Current Level
Time
0
50°
Average EGT Margin

FIG. 6b

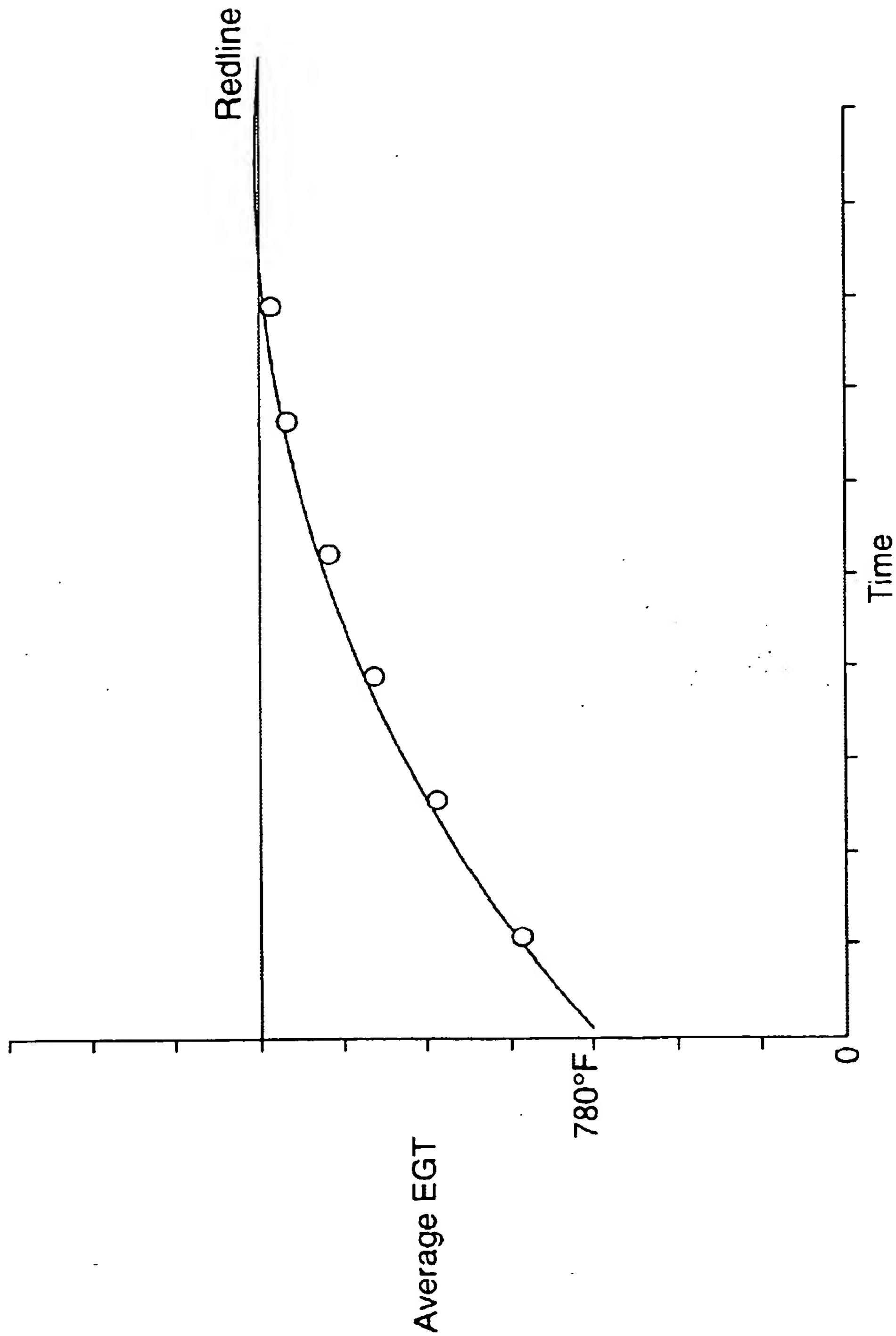
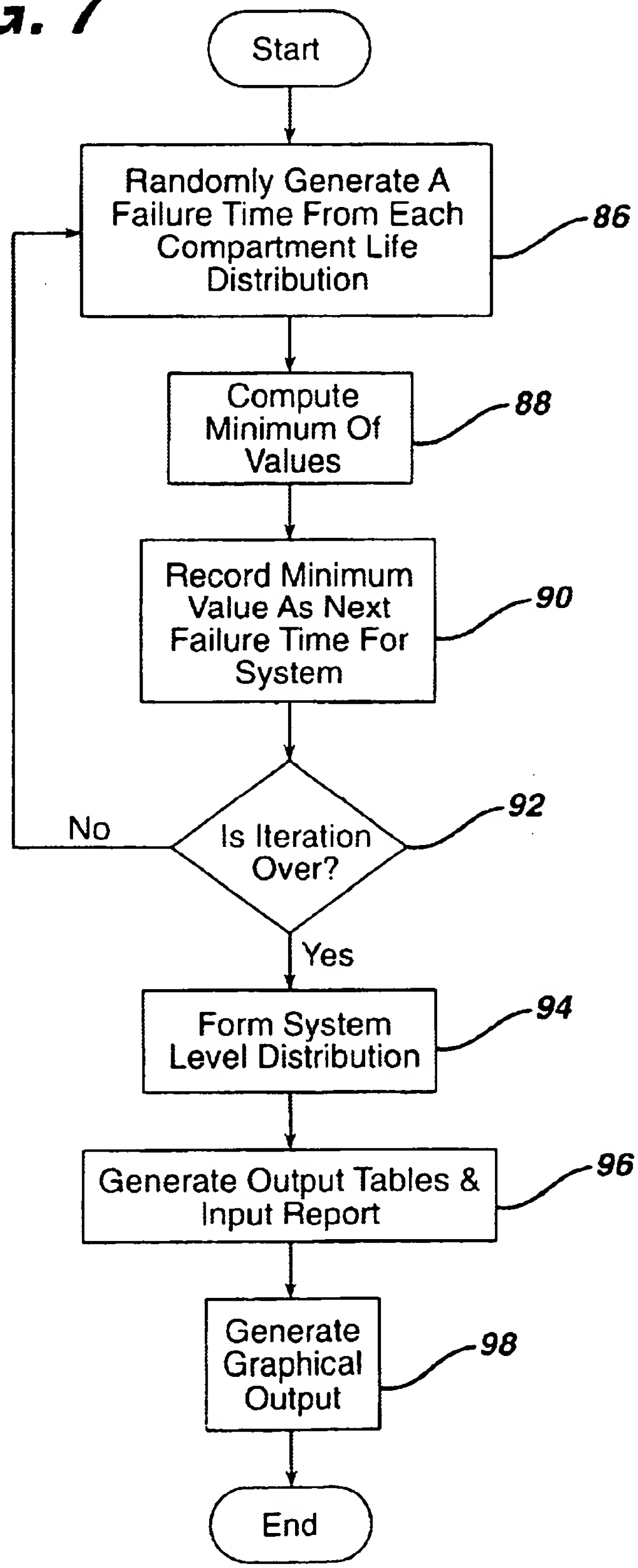


FIG. 7


Start
Randomly Generate A Failure Time From Each Compartment Life Distribution
86
Compute Minimum Of Values
88
Record Minimum Value As Next Failure Time For System
90
Is Iteration Over?
92
No
Yes
Form System Level Distribution
94
Generate Output Tables & Input Report
96
Generate Graphical Output
98
End

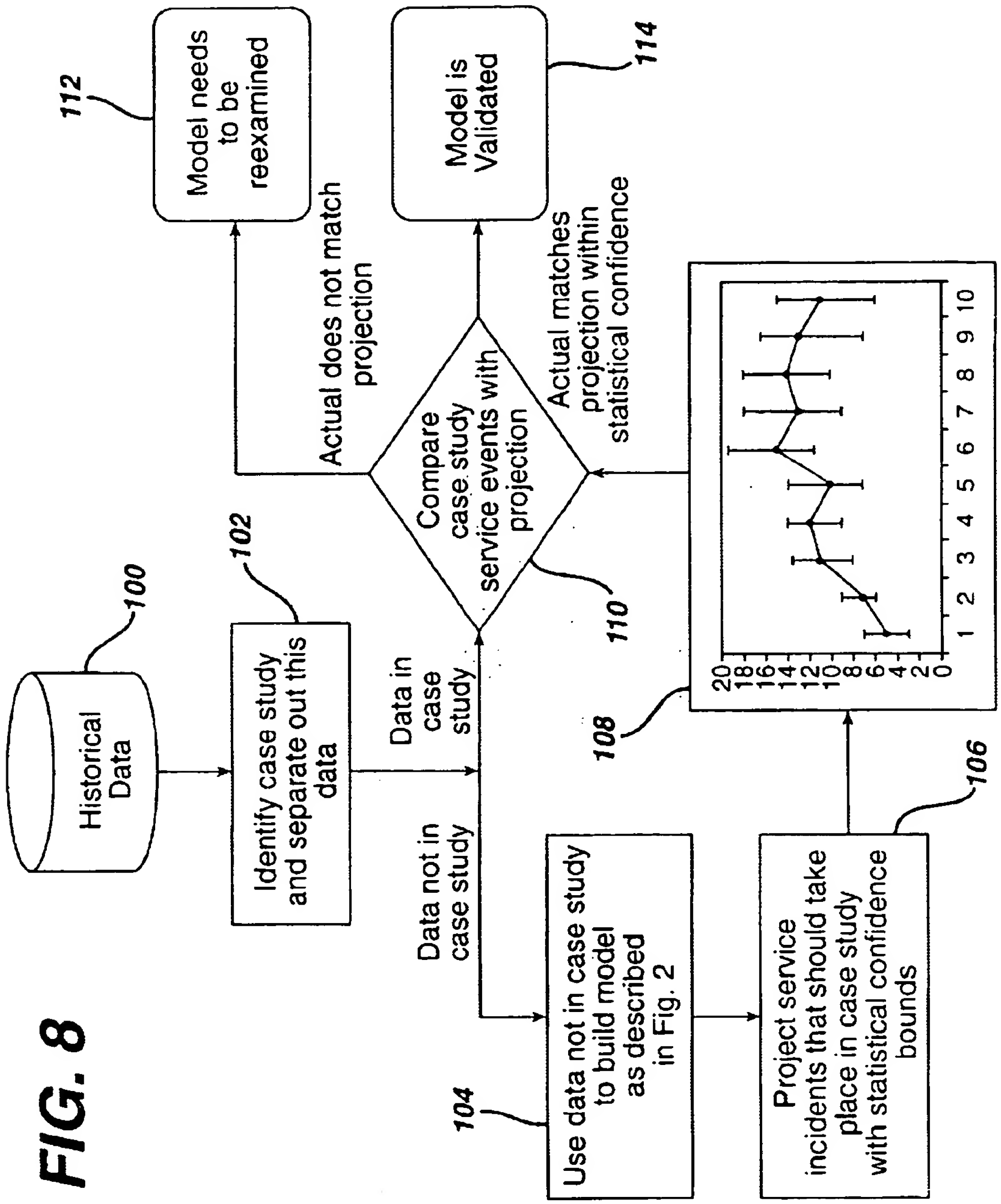

Historical Data
100
Identify case study and separate out this data
102
Data in case study
Data not in case study
Use data not in case study to build model as described in Fig. 2
104
Project service incidents that should take place in case study with statistical confidence bounds
106
108
Compare case study service events with projection
110
Actual does not match projection
Actual matches projection within statistical confidence
Model needs to be reexamined
112
Model is Validated
114
20
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10

FIG. 8

SYSTEM AND METHOD FOR PREDICTING THE TIMING OF FUTURE SERVICE EVENTS OF A PRODUCT

BACKGROUND OF THE INVENTION

This disclosure relates generally to servicing products and systems and more particularly to predicting the timing of future service events of a product or a system.

The market for long-term contractual agreements has grown at high rates over recent years for many of today's service organizations. As the service organizations establish long-term contractual agreements with their customers, it becomes important to understand the expected costs and risks associated with the pricing of service contracts and portfolio management of the contracts. In addition, the service organizations need to have an understanding of the planning of repairs (shop workload planning) and how the introduction of new technology will affect their service contracts. In order to analyze these issues, it is necessary to correctly model the underlying behavior of the product or system so that each can be serviced in the most cost-effective manner.

Currently available analytical practices are unable to accurately model service requirements for complex products or systems. Typically, these models contain poor cost information which result in the service organization inefficiently managing the risk associated with their service portfolios, failing to respond to customer needs and new technology, which all lead to lower long-term contract profitability. A standard time-series method is one particular approach that has been used to model the service requirements of repairable systems such as aircraft engines, automobiles, locomotives and other high tech products. This time-series method examines historical data obtained over a five to ten year period and forms a trend line on either system costs and/or number of repairs made to the system. The trend line is then used to predict future costs and number of repairs. A limitation with this time series method is that it does not give details of failures at a compartmental level. A compartment is a physical or performance related sub-system of the repairable product, which when it fails causes the product to require maintenance or servicing. Other limitations with the standard time series method is that it does not account for the life cycle of the repairable product and thus does not provide a distribution of the expected service events for the product. An analysis based on engineering relationships to determine compartment parameters is another method used to model the service requirements of repairable systems. A limitation with this analysis is that it is not well based in underlying statistics, and thus cannot be shown to accurately model the repairable product on an ongoing basis.

In order to overcome the above problems, there is a need for an approach that can model the service requirements of repairable systems that is accurate and has a comprehensive statistical framework. Such an approach will lead to better cost projections, more realistic and effective risk management, new technology introduction and day-to-day service that is more responsive to customer needs and higher long-term contract profitability.

BRIEF SUMMARY OF THE INVENTION

In accordance with one embodiment of this disclosure, there is a system for predicting the timing of a future service event of a product formed from a plurality of compartments. The system comprises a database that contains a plurality of service information and a plurality of performance information for the product. A statistical analyzer analyzes the plurality of service information to determine a plurality of compartment failure information. A performance deterioration rate analyzer analyzes the performance deterioration rate of the product from the plurality of service information and performance information. A simulator, simulates a distribution of future service events of the product according to the plurality of compartment failure information and the performance deterioration rate analysis.

Similarly, in this disclosure there is a method for predicting the timing of a future service event of a product formed from a plurality of compartments. The method comprises storing a plurality of service information and a plurality of performance information for the product; analyzing the plurality of service information to determine a plurality of compartment failure information; performing a deterioration rate analysis of the product from the plurality of service information and performance information; and simulating a distribution of future service events of the product according to the plurality of compartment failure information and the deterioration rate analysis.

Also, in this disclosure there is a computer-readable medium storing computer instructions for instructing a computer to predict the timing of a future service event of a product formed from a plurality of compartments. The computer instructions comprise storing a plurality of service information and a plurality of performance information for the product; analyzing the plurality of service information to determine a plurality of compartment failure information; performing a deterioration rate analysis of the product from the plurality of service information and performance information and simulating a distribution of future service events of the product according to the plurality of compartment failure information and the deterioration rate analysis.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a schematic of a general purpose computer system in which a system for predicting the timing of future service events of a product operates;

FIG. 2 shows a schematic diagram of a system for predicting the timing of future service events of a product that operates on the computer system shown in FIG. 1;

FIG. 3 shows a flow chart describing actions performed by the system shown in FIG. 2;

FIG. 4 shows a flow chart describing the actions performed by the statistical analyzer shown in FIG. 2;

FIG. 5 shows a flow chart describing the actions performed by the performance deterioration rate analyzer shown in FIG. 2;

FIGS. 6*a*–6*b* show examples of plots that describe some of the performance information stored in the performance historical database shown in FIG. 2;

FIG. 7 shows a flow chart describing the actions performed by the simulator shown in FIG. 2; and

FIG. 8 shows a flow diagram describing the validating actions performed by the system shown in FIG. 2.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 shows a schematic of a general-purpose computer system **10** in which a system for predicting the timing of future service events of a product operates. The computer system **10** generally comprises a processor **12**, a memory **14**, input/output devices, and data pathways (e.g., buses) **16**

connecting the processor, memory and input/output devices. The processor 12 accepts instructions and data from the memory 14 and performs various calculations. The processor 12 includes an arithmetic logic unit (ALU) that performs arithmetic and logical operations and a control unit that extracts instructions from memory 14 and decodes and executes them, calling on the ALU when necessary. The memory 14 generally includes a random-access memory (RAM) and a read-only memory (ROM), however, there may be other types of memory such as programmable read-only memory (PROM), erasable programmable read-only memory (EPROM) and electrically erasable programmable read-only memory (EEPROM). Also, the memory 14 preferably contains an operating system, which executes on the processor 12. The operating system performs basic tasks that include recognizing input, sending output to output devices, keeping track of files and directories and controlling various peripheral devices.

The input/output devices comprise a keyboard 18 and a mouse 20 that enter data and instructions into the computer system 10. A display 22 allows a user to see what the computer has accomplished. Other output devices could include a printer, plotter, synthesizer and speakers. A modem or network card 24 enables the computer system 10 to access other computers and resources on a network. A mass storage device 26 allows the computer system 10 to permanently retain large amounts of data. The mass storage device may include all types of disk drives such as floppy disks, hard disks and optical disks, as well as tape drives that can read and write data onto a tape that could include digital audio tapes (DAT), digital linear tapes (DLT), or other magnetically coded media. The above-described computer system 10 can take the form of a hand-held digital computer, personal digital assistant computer, personal computer, workstation, mini-computer, mainframe computer and supercomputer.

FIG. 2 shows a schematic diagram of a system 28 for predicting the timing of future service events of a product that operates on the computer system 10 shown in FIG. 1. In the system 28, a service database 30 stores a plurality of service information for the product. The plurality of service information varies depending on the product. Generally, the plurality of service information will comprise information such as compartment definitions of the product (i.e., a physical or performance related subsystem that is considered as a unit, which when it fails requires that the product needs maintenance or servicing), repair history of the product (e.g., dates of service events, types of service events, time for a compartment to fail, etc.), as well as any factors which may play a role in explaining the length of time which passes between service events (e.g., environment, operating conditions of the product, product configuration, equipment age, etc.). Other factors may include types of maintenance, cycle time of the product, usage of the product, contract terms and conditions, equipment age and vintage, etc. In this disclosure, the product will be described with reference to an aircraft engine; however, other products such as a power system, a locomotive or any other electrical, chemical or mechanical products, where it is desirable to predict the timing of future service events, may be used.

Referring to FIG. 2, a preprocessor 32 processes the plurality of service information into a predetermined format. The preprocessing includes extracting the plurality of service information from the service database 30; assigning each data record in the database to a compartment depending upon the engineering labeled removal cause; creating new variables from existing variables (e.g., censoring variables, customer indicator variables), deleting outliers and producing summary statistics of the data set (e.g., number of records for each compartment). After performing these acts, the preprocessor 32 generates a plurality of data files according to the service information, wherein each of these data files are formatted as SAS data sets.

A statistical analyzer 34 analyzes the plurality of processed service information to determine a plurality of compartment failure information. The compartment failure information may include statistically significant compartment failure variables and the associated compartment time-to-failure coefficients. Compartment failure variables are variables that affect the time between service or maintenance events. For example, in the aircraft engine scenario, the thrust rating of the engine and the environment that the engine flies in are examples of possible statistically significant compartment failure variables. Compartment time-to-failure coefficients are coefficients that are applied to each of the compartment failure variables. The compartment failure variables and associated compartment time-to-failure coefficients are used to determine the time between servicing events for the compartments. In addition, the statistical analyzer 34 uses this information to determine which compartment failure variables influence service events and estimate time-to-failure distributions for the compartments.

The statistical analyzer 34 comprises several scripts that enable it to perform the aforementioned functions as well as some additional functions. One particular script that the statistical analyzer 34 uses is a service analysis script that executes a plurality of statistical procedures. The plurality of statistical procedures may comprise a multi-variate regression and/or a correlation analysis. Both the multi-variate regression and correlation can determine which compartment failure variables influence the timing of service events and estimate the time-to-failure distributions for the compartments. The statistical analyzer 34 uses other scripts to output this information as well as statistical diagnostics 36 and residual plots 38. The output from the multi-variate regression and/or correlation analysis may include the compartment time-to-failure coefficients for each compartment associated with the product. Other standard output from the multi-variate regression and/or correlation analysis may include a standard error associated with each of the compartment time-to-failure coefficients and a P value, which is an indication of whether a particular variable has a significant effect on the time between occurrences of service events.

Statistical diagnostics that may be outputted include goodness-of-fit metrics and collinearity diagnostics. These enable a user to determine the most appropriate compartment model in the statistical analyzer 34. Residual plots enable a user of the system 28 to determine how well the regression model fits the service information data. Generally, the residual plots are defined as the difference between the actual time until servicing values and the predicted time until servicing values. A small residual value is an indication that the regression or correlation analysis was a good fit, whereas a large residual value is an indication that the fit may be improved.

In addition to residual plots, the statistical analyzer 34 may use another script to output information such as probability plots, which enables one to assess whether the assumed life distribution for each compartment is appropriate or not. Another script may be used to generate a plot of residuals versus each variable that affects the time that a service event occurs.

Referring again to FIG. 2, the system 28 also comprises a performance historical database 40 that includes a plurality

of performance information obtained from the product while in operation. As mentioned above, this disclosure is described with reference to an aircraft engine. Therefore, the performance information can be acquired by using any of a plurality of data acquisition devices such as sensors and transducers. After the data have been obtained, the data acquisition devices can transfer the data to a remote monitoring facility for storage and evaluation. Also, it is possible to have the data from the data acquisition devices manually recorded and entered into the performance historical database **40**. The plurality of performance information includes but is not limited to information such as performance characteristic values (e.g., exhaust gas temperature, EGT), initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of a subset of compartments of the product. For this aircraft engine embodiment, the variables may include flight leg, engine thrust, customer, engine model, engine series, etc. All of this performance information is described below in more detail.

A performance deterioration rate analyzer **42** analyzes the performance characteristic values of the product from both the plurality of service information and performance information. The performance deterioration rate analyzer **42** comprises a statistical analysis script that relates a subset of compartments of the product according to time. For purposes of describing the performance deterioration rate analyzer **42**, time is the amount of time that the aircraft engine is in use. Time can be measured by variables such as cycles or hours. The statistical analysis script generates an estimated deterioration rate curve for a subset of compartments of the product. The performance deterioration rate analyzer **42** further comprises a transformer that transforms each estimated deterioration rate curve for a compartment to a performance life distribution. A performance life distribution is a statistical distribution representing the statistical properties of the time between servicing events and is estimated using performance data as opposed to service data. The performance life distribution is in the same form as the estimated time-to-failure distributions for the compartments determined by the statistical analyzer **34**.

A simulator **44** simulates the future service events of the product according to the plurality of compartment failure information generated by the statistical analyzer **34** and the performance life distribution generated by the performance deterioration rate analyzer **42**. The simulation results in a forecast of the timing of the future service events. In particular, the simulator **44** takes the compartment time-to-failure coefficients from the statistical analyzer **34** and determines a Weibull distribution for each compartment defined for the product. Also, the simulator **44** takes the performance life distribution from the performance deterioration rate analyzer **42** and determines a Weibull distribution for each of the associated compartments defined for the product. The simulator **44** then uses the compartment distributions to determine the overall distribution for the product. Generally, the simulator uses a discrete event-driven Monte Carlo simulation to perform the above operations. After performing the simulation, the simulator **44** generates several outputs. For instance, one output is the contract output **46**, which typically comprises the following: maintenance event distribution parameters over time; demand distributions spare/leased equipment; and equipment performance distributions (e.g., aircraft engine time on wing). The simulator **44** is not limited to these outputs and it is possible to use other outputs if desired.

In order to understand the performance of the simulator **44**, the system **28** uses a validator, which can be part of the statistical analyzer **34** or the simulator or separate from both. The validator contains a validation script prepared for a case study done for the product. For purposes of this disclosure, a case study is defined as any subset of historical service event data that is used for model validation. For example, the service events that took place on a group of randomly chosen systems over the past year may serve as a case study, and during validation, a comparison is a made between the number of service events projected by the model for these systems over this period of time and the actual number of service events that took place. The validation script will compare the compartment distributions determined by the simulator **44** to the distributions that actually happened in the case study. After making the comparison, the validator generates a series of graphical outputs **48** on availability and reliability. In a preferred embodiment, three sets of reliability graphs are generated. The first set of reliability graphs are relative frequency histograms of the actual compartment distributions for each of the first four shop visits for the case study. Overlaid on these relative frequency histograms are the compartment distributions determined by the simulator **44**. The second set of reliability graphs are relative frequency histograms of the actual system level distributions for each of the first four shop visits for the case study. Overlaid on each of these relative frequency histograms are the system distributions determined by the simulator **44**. The third set of reliability graphs are non-parametric Kaplan-Meier estimated survival curves determined from both the actual system level distribution and the system level distribution determined by the simulator **44** for each of the first four shop visits. From these outputs, a user can generate a service plan forecast for the product that comprises time for scheduling service events.

FIG. 3 shows a flow chart describing actions performed by the system **28** shown in FIG. 2. At block **50**, a plurality of service information and performance information for the product stored in the service database and the performance historical database, respectively, are obtained. The preprocessor preprocesses the plurality of service information into a predetermined format at **52**. The statistical analyzer analyzes the plurality of processed service information to determine a plurality of compartment failure information at **54**. In particular, the statistical analyzer determines both the compartment time-to-failure coefficients and the compartment failure variables using the aforementioned statistical procedures. The statistical analyzer outputs the compartment time-to-failure coefficients and the compartment failure variables to the simulator and generates various residual plots.

At the same time the service information are being preprocessed and analyzed by the preprocessor and the statistical analyzer, the performance information are simultaneously evaluated by the performance deterioration rate analyzer. If desired, it is also possible to have the performance information preprocessed in a manner similar to the service information. Regardless of whether the performance information are preprocessed, the performance deterioration rate analyzer runs a deterioration rate analysis at **56**. As mentioned above, the deterioration rate analysis generates an estimated deterioration rate curve for a subset of compartments of the product and transforms each estimated deterioration rate curve to a performance life distribution.

After analyzing the service information and the performance information, the simulator simulates the future service events of the product according to the compartment failure information and the performance life distribution at **58**. In addition, the simulator forecasts or predicts the timing

of the future service events at **60**. As mentioned above, this information is in the form of distributions for each compartment that makes up the product. The validator compares the compartment distributions determined by the simulator to the distributions that actually happened in the case study at **62**. After making the comparison, the validator generates a series of graphical outputs on availability and reliability.

FIG. **4** shows a flow chart describing the actions performed by the statistical analyzer shown in FIG. **2**. At block **64**, the statistical analyzer obtains the service information from the preprocessor. The statistical analyzer then generates compartment definitions for the service information at **66**. At **68**, the statistical analyzer determines compartment failure information such as the statistically significant compartment failure variables and their associated compartment time-to-failure coefficients using the aforementioned statistical procedures. The statistical analyzer then applies the compartment time-to-failure coefficients to the compartment failure variables at **70**. At block **72**, the statistical analyzer generates the various statistical diagnostics for each compartment associated with the product. At block **74**, the statistical analyzer generates residual plots and probability plots and other types of plots if desired. As mentioned above, the statistical analyzer can generate other information such as standard errors associated with each of the compartment time-to-failure coefficients and a P value.

FIG. **5** shows a flow chart describing the actions performed by the performance deterioration rate analyzer **42** shown in FIG. **2**. Before running the deterioration rate analysis, the performance deterioration rate analyzer first obtains the plurality of service information and performance information from the service database and the performance historical database, respectively, at **76**. As mentioned earlier, the plurality of performance information includes information such as performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of each compartment of the product.

FIGS. *6a–6b* show examples describing some of the above-mentioned performance information. In particular, FIG. *6a* shows an example of a deterioration rate curve for a compartment of an aircraft engine. In this example, the compartment is EGT, however, other compartments could be used. For instance, an illustrative but non-exhaustive list could include delta exhaust gas temperature (dEGT), which is the deviation from the baseline EGT, fuel flow (WF), core speed (N2), and EGT divergence, divEGT, which is the difference of the EGT between the raw EGT of the engine in question and the mean of raw EGT of all engines. The deterioration curve shows the degradation of the compartment over time. Eventually, after a period of time, the compartment reaches a level that the degradation is severe enough to warrant servicing. The initial data level performance parameter is the initial level of the compartment after being serviced. In FIG. *6a*, the initial level is about 50° F., and over time the level of the EGT margin will degrade. The historical trending levels are shown in FIG. *6a* as data points. FIG. *6b* shows an example of the raw EGT levels. In particular, FIG. *6b* shows a plot illustrating the removal level or redline for the EGT compartment. The removal level indicates an absolute time that the compartment reaches a predetermined level that necessitates the removal of the aircraft engine for servicing.

Referring back to FIG. **5**, after the service information and the performance information are obtained, the performance deterioration rate analyzer executes the statistical analysis script that relates each compartment of the product according to time at **78**. Preferably, the statistical analysis runs a multi-variate regression analysis for each compartment of the product to identify variables that influence the time between servicing events. An illustrative example of a multi-variate regression analysis using a Weibull distribution is presented. The time (specified either in engine flight hours or engine cycles) between service events is represented as Y. As mentioned earlier, thrust (X1) and flight leg (X2) are two compartment failure variables that might influence the time between service events, Y. The multi-variate Weibull regression model takes the form:

$$\ln(Y)=\alpha+\beta_1 X1+\beta_2 X2+\sigma\epsilon,$$

where ln is the natural log function, ϵ is an error term which follows the smallest extreme value distribution, and α, β_1, β_2, and σ are compartment failure parameters to be estimated from the service data.

For fixed values of thrust (X1) and flight leg (X2), a Weibull distribution representing time between servicing events may be determined. For example, if α=8.9, β_1=−0.00003, β_2=0.75, and σ=0.5 where X1=23500 and X2=1.8, the Weibull distribution of the time between servicing events for this compartment would have a location (or scale) parameter (i.e., the 63.2nd failure percentile) of exp(8.9−0.00003*23500+0.75*1.8)=13975 and a shape parameter equal to 1/σ=1/0.50=2.0. Although a Weibull regression analysis is described, other statistical analyses such as multiple non-linear and loglinear analyses could also be used.

The performance deterioration rate analyzer generates estimated deterioration rate curves for a subset of compartments of the product at **80**. The estimated deterioration rate curves are determined using a multi-variate regression and/or correlation statistical analysis. Denote the performance characteristic (e.g., EGT margin) as Y. One example of a multi-variate regression and/or correlation analysis is presented using Y and time (as measured in cycles) in the following model:

$$Y=\alpha+\beta_1\text{Cycles}+\epsilon$$

where ϵ follows a normal distribution and α and β_1 are parameters to be estimated from the performance and service information data. The estimate of β_1 in this example is an estimated rate of deterioration for the performance characteristic, Y. For example, if β_1=0.003 then the performance characteristic, Y, deteriorates at a approximately 3 degrees per 1000 cycles.

Next, the performance deterioration rate analyzer transforms each estimated deterioration rate curve for the respective compartment to a performance life distribution at **82**. The performance life distribution is characterized by a location (or scale) parameter and a shape parameter. In order to perform the transformation, estimates of α, β_1, and a performance characteristic limit value (i.e., a value at which the compartment requires servicing) which we denote by EGTL, are required. The location (or scale) parameter of the performance life distribution is obtained using the following formula:

$$\text{Location}=\exp\left(\frac{\ln\left(\frac{EGTL-\alpha}{\beta_1}\right)*\ln(-\ln(1-0.825))-\ln\left(\frac{EGTL-\alpha}{\beta_1-\beta_1/3}\right)*\ln(-\ln(1-0.50))}{\ln(-\ln(1-0.825))-\ln(-\ln(1-0.5))}\right)$$

The shape parameter of the performance life distribution is obtained using the following formula:

$$\text{Shape} = \frac{\ln(-\ln(1-0.825))}{\ln\left(\frac{EGTL-\alpha}{\beta_1-\beta_1/3}\right)-\ln(\text{Location})}.$$

As an example, suppose the estimate of α is 0, the estimate of β_1=0.003 and the performance characteristic value is 60. Using the formula above, the location parameter value is estimated to be 23498. The shape parameter is estimated to be 2.27. The performance life distributions for all compartments are then transferred to the simulator at **84**.

FIG. **7** shows a flow chart describing the actions performed by the simulator **44** shown in FIG. **2**. As mentioned earlier, the simulator **44** is interested in determining the distribution of failures at the product's system level so that the timeliness of future service events can be predicted. The simulator **44** is able to determine the distribution of failures at the product's system level because of the information provided by the statistical analyzer **34** and the performance deterioration rate analyzer **42**. The information (i.e., time-to-failure coefficients and compartment variables) provided by the statistical analyzer **34** facilitates an understanding of each of the compartments that make up the product's system level and their relationship with each other, while the performance life distributions provided by the performance deterioration rate analyzer gives more information about probable service requirements. The simulator **44** uses this information to examine the system or aggregate level and predict the overall timing of service events for the product. Referring back to FIG. **7**, the actions performed by the simulator begin at block **86**, where random failure times (i.e., service events) for each compartment distribution are generated. From the randomly generated failure times, the minimum of these values is found at **88**. The simulator designates t_i as the minimum time, where i is the compartment associated with this time value. The simulator then records the minimum time t_i as the next failure time (i.e., time for a service event) for the system level at **90**. At **92**, the simulator determines whether there are any more system level failures needed. If so, then blocks **86**–**90** are repeated a large number of times. Once all of the iterations have been performed, the simulator forms a system level distribution from the failure times at **94**. At **96**, the simulator generates the output tables and the input report, while a graphical output is generated at **98**.

FIG. **8** shows a flow diagram describing the validating actions performed by the system shown in FIG. **1**. In this diagram, historical service event data and the performance historical data are stored in a database at **100**. After identifying a case study, the historical service event data and performance historical data are separated out according to the case study at **102**. If the historical service event data and performance historical data are not in the case study, then this data are used to build a model as described in FIG. **2** at **104**. Project service incidents along with statistical confidence bounds that should take place in the case study are determined at **106**. An example of the project service incidents along with statistical confidence bounds are shown at **108**. The service incidents are compared to data that are used in the case study at **110**. If the actual data do not match the projection, then the model needs to be reexamined as noted at **112**. On the other hand, if the data do match the projection within the statistical confidence bounds, then the model is validated as noted at **114**.

The foregoing flow charts of this disclosure show the architecture, functionality, and operation of a possible implementation of the system for predicting the timing of future service events of a product. In this regard, each block represents a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that in some alternative implementations, the functions noted in the blocks may occur out of the order noted in the figures, or for example, may in fact be executed substantially concurrently or in the reverse order, depending upon the functionality involved.

The above-described system and method for predicting the timing of future service events of a product comprise an ordered listing of executable instructions for implementing logical functions. The ordered listing can be embodied in any computer-readable medium for use by or in connection with a computer-based system that can retrieve the instructions and execute them. In the context of this application, the computer-readable medium can be any means that can contain, store, communicate, propagate, transmit or transport the instructions. The computer readable medium can be, for example but not limited to, an electronic, magnetic, optical, electromagnetic, infrared system, apparatus, or device. An illustrative, but non-exhaustive list of computer-readable mediums can include an electrical connection (electronic) having one or more wires, a portable computer diskette (magnetic), a random access memory (RAM) (magnetic), a read-only memory (ROM) (magnetic), an erasable programmable read-only memory (EPROM or Flash memory) (magnetic), an optical fiber (optical), and a portable compact disc read-only memory (CDROM) (optical). It is even possible to use paper or another suitable medium upon which the instructions are printed. For instance, the instructions can be electronically captured via optical scanning of the paper or other medium, then compiled, interpreted or otherwise processed in a suitable manner if necessary, and then stored in a computer memory.

It is apparent that there has been provided in accordance with this invention, a system and method for predicting the timing of future service events of a product. While the invention has been particularly shown and described in conjunction with a preferred embodiment thereof, it will be appreciated that variations and modifications can be effected by a person of ordinary skill in the art without departing from the scope of the invention.

What is claimed is:

1. A system for predicting the timing of a future service event of a product formed from a plurality of compartments, comprising:

a database that contains a plurality of service information and a plurality of performance information for the product;

a statistical analyzer that analyzes the plurality of service information to determine a plurality of compartment failure information comprising compartment failure variables and compartment time-to-failure coefficients, wherein the stastistical analyzer uses the plurality of compartment failure information to determine which compartment failure variables influence the timing of future service events and estimate time-to-failure distributions for the plurality of compartments;

a performance deterioration rate analyzer that analyzes performance deterioration rate of the product from the plurality of service information and performance information, wherein the performance deterioration rate analyzer comprises a statistical analysis script that relates performance information of a subset of compartments of the product according to time, wherein the

statistical analysis script generates an estimated deterioration rate curve for the subset of compartments of the product, wherein the performance deterioration rate analyzer further comprises a transformer that transforms each estimated deterioration rate curve for a compartment to a performance life distribution; and

a simulator for simulating a distribution of future service events of the product according to the time-to-failure distributions and performance life distributions plurality.

2. The system according to claim 1, wherein the database comprises a service database and a performance historical database.

3. The system according to claim 1, wherein the plurality of performance information comprises compartment definitions, repair history and service factors.

4. The system according to claim 1, wherein the plurality of performance information comprises performance characteristic values, initial data levels after servicing, currant data levels, dales at which the product is serviced, and variables that affect the servicing of a subset of the plurality of compartments.

5. The system according in claim 1, further comprising a preprocessor for processing the plurality of service information into a predetermined format.

6. The system according to claim 5, wherein the preprocessor generates a plurality of data files according to the plurality of service information.

7. The system accosting to claim 1, wherein the statistical analyzer uses the estimated time-to-fallure distributions to determine a Weibull distribution for a subset of the plurality of compartments defined to the product.

8. The system according to claim 1, wherein the statistical analyzer comprises a service analysis script that executes a plurality of statistical procedures.

9. The system according to claim 8, wherein the plurality of statistical procedures comprise a multivariate regression and/or a correlation analysis.

10. The system according to claim 8, wherein the service analysis script generates a plurality of statistical diagnostic information.

11. The system according to claim 10, wherein the plurality of statistical diagnostic information comprises goodness-of-fit metrics and collinearity diagnostics.

12. The system according to claim 8, wherein the service analysis script generates a plurality of residual plots.

13. The system according to claim 1, wherein the statistical analyzer comprises a validation script.

14. The system according to claim 13, wherein the validation script is applied to a plurality of case studies set up for the product.

15. The system according to claim 1, wherein the simulator uses the performance life distributions to determine a Weibull distribution for a subset of the plurality of compartments defined for the product.

16. The system according to claim 1, wherein the simulator forecasts a service plan for the future service events that comprises the time for scheduling the service events.

17. A system for predicting the timing of a future service event of a product formed from a plurality of compartments, comprising:

means for containing a plurality of service information end a plurality of performance information for the product;

means for analyzing the plurality of service information to determine a plurality of compartment failure information comprising compartment failure variables and compartment time-to-failure coefficients, wherein the analyzing means uses the plurality of compartment failure information to determine which compartment failure variables influence the timing of future service events and estimate time-to-failure distributions for the compartments;

means for performing a deterioration rate analysis that determines performance deterioration rate of the product from the plurality of service information and performance information, wherein the performing means comprises a statistical analysis script that relates performance information of a subset of the plurality of compartments of the product according to time, wherein the statistical analysis script generates an estimated deterioration rate curve for a subset of the plurality of compartments of the product, wherein the performing means further comprises means for transforming each estimated deterioration rate curve for a compartment to a performance life distribution; and

means for simulating a distribution of future service events of the product according to the time-to-failure distributions and performance life distributions plurality of compartment.

18. The system according to claim 17, wherein the plurality of service information comprises compartment definitions, repair history and service factors.

19. The system according to claim 17, wherein the plurality of performance information comprises performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that effect the servicing of a subset of the plurality of compartments of the product.

20. The system according to claim 17, further comprising means for preprocessing the plurality of service information into a predetermined format.

21. The system according to claim 17, wherein the preprocessing means generates a plurality of data files according to the plurality of service information.

22. The system according to claim 17, wherein the analyzing means uses the estimated time-to-failure distributions to determine a Weibull distribution for a subset of the plurality of compartments defined for the product.

23. The system according to claim 17, wherein the analyzing means comprises a service analysis script that executes a plurality of statistical procedures.

24. The system according to claim 23, wherein the plurality of statistical procedures comprise a multivariate regression and/or a correlation analysis.

25. The system according to claim 23, wherein the service analysis script generates a plurality of statistical diagnostic information.

26. The system according to claim 25, wherein the plurality of statistical diagnostic information comprises goodness-of-fit metrics and collinearity diagnostics.

27. The system according to claim 23, wherein the service analysis script generates a plurality of residual plots.

28. The system according to claim 17, wherein the analyzing means comprises a validation script.

29. The system according to claim 28, wherein the validation script is applied to a plurality of case studies set up for the product.

30. The system according to claim 17, wherein the simulator uses the performance life distribution to determine a Weibull distribution for a subset of the plurality of compartments defined for the product.

31. The system according to claim 17, wherein the simulator forecasts a service plan for the future service events that comprises the time for scheduling the service events.

32. A method for predicting the timing of a future service event of a product formed from a plurality of compartments, comprising;

storing a plurality of service information and a plurality of performance information for the product;

analyzing the plurality of service information to determine a plurality of compartment failure information comprising compartment failure variables and compartment time-to-failure coefficients, wherein the analyzing uses the plurality of compartment failure information to determine which compartment failure variables influence the timing of future service events and estimate time-to-failure distributions for the plurality of compartments;

performing a deterioration rate analysis of the product from the plurality of service information and performance information, wherein the performing comprises using a statistical analysis script that relates performance information of a subset of the plurality of compartments of the product according to time, wherein the statistical analysis script generates an estimated deterioration rate curve for a subset of the plurality of compartments of the product, wherein the performing a deterioration rate analysis further comprises transforming each estimated deterioration rate curve for a compartment to a performance life distribution; and

simulating a distribution of future service events of the product according to the time-to-failure distributions and performance life distributions.

33. The method according to claim 32, wherein the plurality of service information comprises compartment definitions, repair history and service factors.

34. The method according to claim 32, wherein the plurality of performance information comprises performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of a subset of the plurality of compartments of the product.

35. The method according to claim 32, further comprising preprocessing the plurality of service information into a predetermined format.

36. The method according to claim 35, wherein the preprocessing generates a plurality of data files according to the plurality of service information.

37. The method according to claim 32, wherein the analyzing uses the estimated time-to-failure distributions to determine a Weibull distribution for a subset of the plurality of compartments.

38. The method according to claim 32, wherein the analyzing comprises using a service analysis script that executes a plurality of statistical procedures.

39. The method according to claim 38, a wherein the plurality of statistical procedures comprise a multivariate regression and/or a correlation analysis.

40. The method according to claim 39, wherein the service analysis script generates a plurality of statistical diagnostic information.

41. The method according to claim 40, wherein the plurality of statistical diagnostic intonation comprises goodness-of-fit metrics and collinearity diagnostics.

42. The method according to claim 38, wherein the service analysis script generating a plurality of residual plots.

43. The method according to claim 32 wherein the analyzing comprises using a validation script.

44. The method according to claim 43, wherein the validation script is applied to a plurality of case studies set up for the product.

45. The method according to claim 32, wherein the simulating uses the performance life distributions to determine a Weibull distribution for a subset of the plurality of compartments.

46. The method according to claim 32, wherein the simulating forecasts a service plan for the future service events that comprises the time for scheduling the service events.

47. A computer-readable medium storing computer instructions which when executed on a computer system predict the timing of a future service event of a product formed from a plurality of compartments, the computer instructions comprising:

storing a plurality of service information and a plurality of performance information for the product;

analyzing the plurality of service information to determine a plurality of compartment failure information comprising compartment failure variables and compartment time-to-failure coefficients, wherein the analyzing instructions uses the plurality of compartment failure information to determine which compartment failure variables influence the timing of future service events and estimates time-to-failure distributions for the plurality of compartments;

performing a deterioration rate analysis of the product from the plurality of service information and performance information, wherein the performing instructions comprise using a statistical analysis script that relates performance information of a subset of the plurality of compartments of the product according to time, wherein the statistical analysis script generates an estimated deterioration rate curve for a subset of the plurality of compartments of the product, wherein the performing instructions further comprise transforming instructions that transform each estimated deterioration rate curve to a performance life distribution; and

simulating a distribution of future service events of the product according to the time-to-failure distributions and performance life distributions.

48. The computer-readable medium according to claim 47, wherein the plurality of service information comprises compartment definitions, repair history and service factors.

49. The computer-readable medium according to claim 47, wherein the plurality of performance information comprises performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of a subset of the plurality of compartments of the product.

50. The computer-readable medium according to claim 47, further comprising preprocessing instructions that preprocess the plurality of service information into a predetermined format.

51. The computer-readable medium according to claim 50, wherein the preprocessing instructions generates a plurality of data files according to the plurality of service information.

52. The computer-readable medium according to claim 47, wherein the analyzing instructions use the estimated time-to-failure distributions to determine a Weibull distribution for a subset of the plurality of compartments.

53. The computer-readable medium according to claim 47, wherein the analyzing instructions comprises instructions for using a service analysis script that executes a plurality of statistical procedures.

54. The computer-readable medium according to claim 53, wherein the plurality of statistical procedures comprise a multivariate regression and/or a correlation analysis.

55. The computer-readable medium according to claim 54, wherein the service analysts script generates a plurality of statistical diagnostic information.

56. The computer-readable medium according to claim 55, wherein the plurality of statistical diagnostic information comprises goodness-of-fit metrics and collinearity diagnostics.

57. The computer-readable medium according to claim 53, wherein the service analysis script generates a plurality of residual plots.

58. The computer-readable medium according to claim 47, wherein the analyzing instructions comprise using a validation script.

59. The computer-readable medium according to claim 58, wherein the validation script is applied to a plurality of case studies set up for the product.

60. The computer-readable medium according to claim 47, wherein the simulating instructions use the performance life distribution to determine a Weibull distribution for a subset of the plurality of compartments.

61. The computer-readable medium according to claim 47, wherein the simulating instructions forecasts a service plan far the future service events that comprises the time for scheduling the service events.

* * * * *

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor: Aragones et al.

Serial No.: 09/578,095 Group Art Unit: 2123

Filed: May 25, 2000 Examiner: Thangavelu

Title: System And Method For Predicting Timing Of Future Service Of A Product

Response to Paper No.: 3

AMENDMENT UNDER 37 CFR §1.111

Mail Stop Non-Fee Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 2213-1450

Sir:

In response to the Office Action mailed on September 25, 2003, Applicant proposes the following amendment for the above-identified patent application:

Amendments to the claims are reflected in the listing of claims which begins on page 2 of this correspondence.

Remarks begin on page 15 of this correspondence.

Amendment To The Claims

Below is a listing of the claims that will replace all prior versions and listings of claims in the present patent application.

1. (Currently Amended) A system for predicting the timing of a future service event of a product formed from a plurality of compartments, comprising:

a database that contains a plurality of service information and a plurality of performance information for the product;

a statistical analyzer that analyzes the plurality of service information to determine a plurality of compartment failure information comprising compartment failure variables and compartment time-to-failure coefficients, wherein the statistical analyzer uses the plurality of compartment failure information to determine which compartment failure variables influence the timing of future service events and estimate time-to-failure distributions for the plurality of compartments;

a performance deterioration rate analyzer that analyzes performance deterioration rate of the product from the plurality of service information and performance information, wherein the performance deterioration rate analyzer comprises a statistical analysis script that relates a subset of compartments of the product according to time, wherein the statistical analysis script generates an estimated deterioration rate curve for the subset of compartments of the product, wherein the performance deterioration rate analyzer further comprises a transformer that transforms each estimated deterioration rate curve for a compartment to a performance life distribution; and

a simulator for simulating a distribution of future service events of the product according to the time-to-failure distributions and performance life distributions ~~plurality of compartment failure information and the performance deterioration rate analysis~~.

2. (Original) The system according to claim 1, wherein the database comprises a service database and a performance historical database.

3. (Original) The system according to claim 1, wherein the plurality of service information comprises compartment definitions, repair history and service factors.

4. (Original) The system according to claim 1, wherein the plurality of performance information comprises performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of a subset of the plurality of compartments.

5. (Original) The system according to claim 1, further comprising a preprocessor for processing the plurality of service information into a predetermined format.

6. (Currently Amended) The system according to claim 5 [[1]], wherein the preprocessor generates a plurality of data files according to the plurality of service information.

7. (Canceled)

8. (Canceled)

9. (Currently Amended) The system according to claim 1 [[8]], wherein the statistical analyzer uses the estimated time-to-failure distributions to determine a Weibull distribution for a subset of the plurality of compartments defined for the product.

10. (Original) The system according to claim 1, wherein the statistical analyzer comprises a service analysis script that executes a plurality of statistical procedures.

11. (Original) The system according to claim 10, wherein the plurality of statistical procedures comprise a multivariate regression and/or a correlation analysis.

12. (Original) The system according to claim 10, wherein the service analysis script generates a plurality of statistical diagnostic information.

13. (Original) The system according to claim 12, wherein the plurality of statistical diagnostic information comprises goodness-of-fit metrics and collinearity diagnostics.

14. (Original) The system according to claim 10, wherein the service analysis script generates a plurality of residual plots.

15. (Original) The system according to claim 1, wherein the statistical analyzer comprises a validation script.

16. (Original) The system according to claim 15, wherein the validation script is applied to a plurality of case studies set up for the product.

17. (Canceled)

18. (Canceled)

19. (Canceled)

20. (Currently Amended) The system according to claim 1 [[19]], wherein the simulator uses the performance life distributions to determine a Weibull distribution for a subset of the plurality of compartments defined for the product.

21. (Original) The system according to claim 1, wherein the simulator forecasts a service plan for the future service events that comprises the time for scheduling the service events.

22. (Currently Amended) A system for predicting the timing of a future service event of a product formed from a plurality of compartments, comprising:

means for containing a plurality of service information and a plurality of performance information for the product;

means for analyzing the plurality of service information to determine a plurality of compartment failure information comprising compartment failure variables and compartment time-to-failure coefficients, wherein the analyzing means uses the plurality of compartment failure information to determine which compartment failure variables influence the timing of future service events and estimate time-to-failure distributions for the compartments;

means for performing a deterioration rate analysis that determines performance deterioration rate of the product from the plurality of service

information and performance information, wherein the performing means comprises a statistical analysis script that relates a subset of the plurality of compartments of the product according to time, wherein the statistical analysis script generates an estimated deterioration rate curve for a subset of the plurality of compartments of the product, wherein the performing means further comprises means for transforming each estimated deterioration rate curve for a compartment to a performance life distribution; and

means for simulating a distribution of future service events of the product according to the time-to-failure distributions and performance life distributions ~~plurality of compartment failure information and the performance deterioration rate analysis~~.

23. (Original) The system according to claim 22, wherein the plurality of service information comprises compartment definitions, repair history and service factors.

24. (Original) The system according to claim 22, wherein the plurality of performance information comprises performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of a subset of the plurality of compartments of the product.

25. (Original) The system according to claim 22, further comprising means for preprocessing the plurality of service information into a predetermined format.

26. (Original) The system according to claim 25, wherein the preprocessing means generates a plurality of data files according to the plurality of service information.

27. (Canceled)

28. (Canceled)

29. (Currently Amended) The system according to claim 22 [[28]], wherein the analyzing means uses the estimated time-to-failure distributions to determine a Weibull distribution for a subset of the plurality of compartments defined for the product.

30. (Original) The system according to claim 22, wherein the analyzing means comprises a service analysis script that executes a plurality of statistical procedures.

31. (Original) The system according to claim 30, wherein the plurality of statistical procedures comprise a multivariate regression and/or a correlation analysis.

32. (Currently Amended) The system according ~~systemaccording~~ to claim 30, wherein the service analysis script generates a plurality of statistical diagnostic information.

33. (Original) The system according to claim 32, wherein the plurality of statistical diagnostic information comprises goodness-of-fit metrics and collinearity diagnostics.

34. (Original) The system according to claim 30, wherein the service analysis script generates a plurality of residual plots.

35. (Original) The system according to claim 22, wherein the analyzing means comprises a validation script.

36. (Original) The system according to claim 35, wherein the validation script is applied to a plurality of case studies set up for the product.

37. (Canceled)

38. (Canceled)

39. (Canceled)

40. (Currently Amended) The system according to claim <u>22</u> [[39]], wherein the simulator uses the performance life distribution to determine a Weibull distribution for a subset of the plurality of compartments defined for the product.

41. (Original) The system according to claim 22, wherein the simulator forecasts a service plan for the future service events that comprises the time for scheduling the service events.

42. (Currently Amended) A method for predicting the timing of a future service event of a product formed from a plurality of compartments, comprising;

storing a plurality of service information and a plurality of performance information for the product;

analyzing the plurality of service information to determine a plurality of compartment failure information <u>comprising compartment failure variables and</u>

compartment time-to-failure coefficients, wherein the analyzing uses the plurality of compartment failure information to determine which compartment failure variables influence the timing of future service events and estimate time-to-failure distributions for the plurality of compartments;

performing a deterioration rate analysis of the product from the plurality of service information and performance information, wherein the performing comprises using a statistical analysis script that relates a subset of the plurality of compartments of the product according to time, wherein the statistical analysis script generates an estimated deterioration rate curve for a subset of the plurality of compartments of the product, wherein the performing a deterioration rate analysis further comprises transforming each estimated deterioration rate curve for a compartment to a performance life distribution; and

simulating a distribution of future service events of the product according to the time-to-failure distributions and performance life distributions ~~plurality of compartment failure information and the performance deterioration rate analysis~~.

43. (Original) The method according to claim 42, wherein the plurality of service information comprises compartment definitions, repair history and service factors.

44. (Original) The method according to claim 42, wherein the plurality of performance information comprises performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of a subset of the plurality of compartments of the product.

45. (Original) The method according to claim 42, further comprising preprocessing the plurality of service information into a predetermined format.

46. (Original) The method according to claim 45, wherein the preprocessing generates a plurality of data files according to the plurality of service information.

47. (Canceled)

48. (Canceled)

49. (Currently Amended) The method according to claim 42 [[48]], wherein the analyzing uses the estimated time-to-failure distributions to determine a Weibull distribution for a subset of the plurality of compartments.

50. (Original) The method according to claim 42, wherein the analyzing comprises using a service analysis script that executes a plurality of statistical procedures.

51. (Original) The method according to claim 50, wherein the plurality of statistical procedures comprise a multivariate regression and/or a correlation analysis.

52. (Original) The method according to claim 51, wherein the service analysis script generates a plurality of statistical diagnostic information.

53. (Original) The method according to claim 52, wherein the plurality of statistical diagnostic information comprises goodness-of-fit metrics and collinearity diagnostics.

54. (Original) The method according to claim 50, wherein the service analysis script generates a plurality of residual plots.

55. (Original) The method according to claim 42, wherein the analyzing comprises using a validation script.

56. (Original) The method according to claim 55, wherein the validation script is applied to a plurality of case studies set up for the product.

57. (Canceled)

58. (Canceled)

59. (Canceled)

60. (Currently Amended) The method according to claim 42 [[59]], wherein the simulating uses the performance life distributions to determine a Weibull distribution for a subset of the plurality of compartments.

61. (Original) The method according to claim 42, wherein the simulating forecasts a service plan for the future service events that comprises the time for scheduling the service events.

62. (Currently Amended) A computer-readable medium storing computer instructions for instructing a computer system to predict the timing of a future service event of a product formed from a plurality of compartments, the computer instructions comprising:

storing a plurality of service information and a plurality of performance information for the product;

analyzing the plurality of service information to determine a plurality of compartment failure information comprising compartment failure variables and compartment time-to-failure coefficients, wherein the analyzing instructions uses the plurality of compartment failure information to determine which compartment failure variables influence the timing of future service events and estimate time-to-failure distributions for the plurality of compartments;

performing a deterioration rate analysis of the product from the plurality of service information and performance information, wherein the performing instructions comprise a statistical analysis script that relates a subset of the plurality of compartments of the product according to time, wherein the statistical analysis script generates an estimated deterioration rate curve for a subset of the plurality of compartments of the product, wherein the performing instructions further comprise transforming instructions that transform each estimated deterioration rate curve to a performance life distribution; and

simulating a distribution of future service events of the product according to the time-to-failure distributions and performance life distributions ~~plurality of compartment failure information and the performance deterioration rate analysis~~.

63. (Original) The computer-readable medium according to claim 62, wherein the plurality of service information comprises compartment definitions, repair history and service factors.

64. (Original) The computer-readable medium according to claim 62, wherein the plurality of performance information comprises performance characteristic values, initial data levels after servicing, current data levels, dates at which the product is serviced, and variables that affect the servicing of a subset of the plurality of compartments of the product.

65. (Original) The computer-readable medium according to claim 62, further comprising preprocessing instructions that preprocess the plurality of service information into a predetermined format.

66. (Original) The computer-readable medium according to claim 65, wherein the preprocessing instructions generates a plurality of data files according to the plurality of service information.

67. (Canceled)

68. (Canceled)

69. (Currently Amended) The computer-readable medium according to claim <u>62</u> [[68]], wherein the analyzing instructions use the estimated time-to-failure distributions to determine a Weibull distribution for a subset of the plurality of compartments.

70. (Original) The computer-readable medium according to claim 62, wherein the analyzing instructions comprises instructions for using a service analysis script that executes a plurality of statistical procedures.

71. (Original) The computer-readable medium according to claim 70, wherein the plurality of statistical procedures comprise a multivariate regression and/or a correlation analysis.

72. (Original) The computer-readable medium according to claim 71, wherein the service analysis script generates a plurality of statistical diagnostic information.

73. (Original) The computer-readable medium according to claim 72, wherein the plurality of statistical diagnostic information comprises goodness-of-fit metrics and collinearity diagnostics.

74. (Original) The computer-readable medium according to claim 70, wherein the service analysis script generates a plurality of residual plots.

75. (Original) The computer-readable medium according to claim 62, wherein the analyzing instructions comprise using a validation script.

76. (Original) The computer-readable medium according to claim 75, wherein the validation script is applied to a plurality of case studies set up for the product.

77. (Canceled)

78. (Canceled)

79. (Canceled)

80. (Currently Amended) The computer-readable medium according to claim <u>62</u> [[79]], wherein the simulating instructions use the performance life distribution to determine a Weibull distribution for a subset of the plurality of compartments.

81. (Original) The computer-readable medium according to claim 62, wherein the simulating instructions forecasts a service plan for the future service events that comprises the time for scheduling the service events.

Remarks

Applicant carefully considered the Office Action mailed on September 25, 2003. Claims 1-81 are pending in the present patent application. Of the pending claims, the Examiner rejected claims 1-81. In response to the Office Action, Applicant canceled claims 7-8, 17-19; 27-28, 37-39; 47-48, 57-59; and 67-68, 77-79 and incorporated the subject matter therefrom into independent claims 1, 22, 42, and 62, respectively, to overcome the 35 USC §103 rejections. Also, Applicant added extra limitations to claims 1, 22, 42, and 62 to further distinguish over the prior art. In addition, Applicant amended claims 9, 20, 29, 40, 49, 60, 69 and 80 to maintain proper claim dependency. Also, Applicant amended claims 6 and 32 to correct minor inconsistencies. No new matter has been added. Applicant requests further examination and reconsideration of the present patent application.

The Examiner rejected claims 1-3, 5-8, 22, 23, 25-28, 42, 43, 45-48, 62, 63 and 65-68 under 35 USC §103(a) as being unpatentable over Kaminsky et al. ("A Monte Carlo Approach To Warranty Repair Predictions") in view of Cribbes ("Changes In Engine Maintenance Management") and further in view of Endrenyi et al.

Independent claims 1, 22, 42 and 62 now recite that the simulation of a distribution of future service events are based on estimated time-to-failure distributions and performance life distributions. The combination of Kaminsky et al. (hereinafter Kaminsky) in view of Cribbes and further in view of Endrenyi et al. (hereinafter Endrenyi) does not disclose or suggest performing a simulation based on estimated time-to-failure distributions and performance life distributions. Instead, the simulation performed by the combination of Kaminsky, Cribbes and Endrenyi is based on time-to-failure distributions. The combination of Kaminsky, Cribbes and Endrenyi does not provide a motivation suggesting the desirability of performing a simulation based on both time-to-failure distributions

and performance life distributions. Furthermore, Applicant submits that it would not have been obvious to one of ordinary skill in the art at the time of the invention to use performance life distributions in addition to time-to-failure distributions to simulate future service events in light of the teachings provided in Kaminsky, Cribbes and Endrenyi.

Since the combination of Kaminsky, Cribbes and Endrenyi does not disclose or suggest simulation of future service events based on estimated time-to-failure distributions and performance life distributions as set forth in claims 1, 22, 42 and 62, Applicant submits that these claims are patentably distinguishable over the combination. Therefore, Applicant requests that the Examiner reconsider and remove the §103(a) rejection of claims 1, 22, 42 and 62 under the combination of Kaminsky, Cribbes and Endrenyi.

Claims 2-3, 5-6; 23, 25-26; 43, 45-46; and 63, 65-66 depend directly or indirectly from now presumably allowable claims 1, 22, 42 and 62, respectively. Accordingly, Applicant requests that the Examiner reconsider and remove the §103(a) rejection of these claims.

Applicant notes that the Examiner submitted that the combination of Kaminsky in view of Cribbes and further in view of Endrenyi, Butler ("An Expert System Based Framework For An Incipient Failure Detection And Preventive Maintenance System") and Wang (US Patent Number 6,230,095) discloses the limitation of estimating deterioration rate curves for a subset of compartments of the product and transforming the deterioration rate curves to a performance life distribution. Applicant submits that the combination of Kaminsky in view of Cribbes and further in view of Endrenyi, Butler and Wang does not disclose or suggest estimating deterioration rate curves for a subset of compartments in a product and transforming the deterioration rate curves to a performance life distribution. The Examiner referenced the abstract, col. 2, lines 22-37 in Wang as being relevant to the limitation of estimating deterioration rate curves for a subset of compartments in a product. Applicant carefully reviewed these

sections in Wang and submits that they do not suggest estimating deterioration rate curves for a subset of compartments. Instead, Wang teaches that the rate and magnitude of deterioration of an engine is indicated by a trend parameter. An indication of deterioration through the use of a trend parameter is not analogous to estimating deterioration rate curves for a subset of compartments. With regard to transforming the deterioration rate curves to a performance life distribution, the Examiner referenced page 321, column 1, paragraph 5 to column 2, paragraph 1 in Butler as being relevant to this limitation. Applicant carefully reviewed this section in Butler and submits that it does not disclose or suggest transforming deterioration rate curves for a subset of compartments to a performance life distribution. Instead, Butler relates to detecting incipient failure on distribution systems or equipment. Butler provides no teaching or motivation suggesting the desirability of transforming deterioration rate curves to a performance life distribution.

In view of these distinctions, Applicant submits that the combination of Kaminsky in view of Cribbes and further in view of Endrenyi, Butler and Wang does not disclose or suggest estimating deterioration rate curves for a subset of compartments of the product and transforming the deterioration rate curves to a performance life distribution. In addition, Applicant submits that the combination of Kaminsky in view of Cribbes and further in view of Endrenyi, Butler and Wang does not suggest simulating a distribution of future service events based on estimated time-to-failure distributions and performance life distributions. Furthermore, Applicant submits that it would not have been obvious to one of ordinary skill in the art at the time of the invention to use performance life distributions in addition to time-to-failure distributions to simulate a distribution of future service events, in light of the teachings provided in the combination of Kaminsky in view of Cribbes and further in view of Endrenyi, Butler and Wang.

The Examiner rejected claims 4, 21, 24, 41, 44, 61, 64 and 81 under 35 U.S.C. §103(a) as being unpatentable over Kaminsky in view of Cribbes and further in view of Endrenyi and the Aerospace Technology article entitled

"Forecasting Engine Removals and Shop Visits" (hereinafter Aerospace Technology). The Examiner added the Aerospace Technology article for its disclosure of certain performance information. The Aerospace Technology article provides no teaching or motivation that suggests the desirability of performing a simulation of a distribution of future service events based on estimated time-to-failure distributions and performance life distributions derived from deterioration rate curves as set forth in claims 1, 22, 42 and 62. Since claims 4, 21; 24, 41; 44, 61; and 64, 81 depend from presumably allowable claims 1, 22, 42 and 62, respectively, Applicant submits that these claims are allowable by dependency and requests that the Examiner reconsider and remove the §103(a) rejection.

The Examiner rejected claims 9, 29, 49, and 69 under 35 U.S.C. §103(a) as being unpatentable over Kaminsky in view of Cribbes and further in view of Endrenyi and Woodman et al. (US Patent Number 6,195,624). The Examiner added Woodman et al. (hereinafter Woodman) for its disclosure of determining a Weibull distribution. Woodman provides no teaching or motivation that suggests the desirability of performing a simulation of a distribution of future service events based on estimated time-to-failure distributions and performance life distributions derived from deterioration rate curves as set forth in claims 1, 22, 42 and 62. Since claims 9, 29, 49, and 69 depend from presumably allowable claims 1, 22, 42 and 62, respectively, Applicant submits that these claims are allowable by dependency and requests that the Examiner reconsider and remove the §103(a) rejection.

The Examiner rejected claims 10, 30, 50, and 70 under 35 U.S.C. §103(a) as being unpatentable over Kaminsky in view of Cribbes and further in view of Endrenyi and Subramanyam (US Patent Number 5,701,471). The Examiner added Subramanyam for its disclosure of using certain statistical procedures. Subramanyam provides no teaching or motivation that suggests the desirability of performing a simulation of a distribution of future service events based on estimated time-to-failure distributions and performance life distributions derived

from deterioration rate curves as set forth in claims 1, 22, 42 and 62. Since claims 10, 30, 50, and 70 depend from presumably allowable claims 1, 22, 42 and 62, respectively, Applicant submits that these claims are allowable by dependency and requests that the Examiner reconsider and remove the §103(a) rejection.

The Examiner rejected claims 11, 31, 51, and 71 under 35 U.S.C. §103(a) as being unpatentable over Kaminsky in view of Cribbes and further in view of Endrenyi, Subramanyam and Djaja et al. (US Patent Number 6,405,160). The Examiner added Djaja et al. (hereinafter Djaja) for its disclosure of using multivariate regression and/or correlation analysis. Djaja provides no teaching or motivation that suggests the desirability of performing a simulation of a distribution of future service events based on estimated time-to-failure distributions and performance life distributions derived from deterioration rate curves as set forth in claims 1, 22, 42 and 62. Since claims 11, 31, 51, and 71 depend from presumably allowable claims 1, 22, 42 and 62, respectively, Applicant submits that these claims are allowable by dependency and requests that the Examiner reconsider and remove the §103(a) rejection.

The Examiner rejected claims 12, 32, 52, and 72 under 35 U.S.C. §103(a) as being unpatentable over Kaminsky in view of Cribbes and further in view of Endrenyi, Subramanyam and Cave et al. (US Patent Number 5,740,233). The Examiner added Cave et al. (hereinafter Cave) for its disclosure of generating certain statistical diagnostic information. Cave provides no teaching or motivation that suggests the desirability of performing a simulation of a distribution of future service events based on estimated time-to-failure distributions and performance life distributions derived from deterioration rate curves as set forth in claims 1, 22, 42 and 62. Since claims 12, 32, 52, and 72 depend from presumably allowable claims 1, 22, 42 and 62, respectively, Applicant submits that these claims are allowable by dependency and requests that the Examiner reconsider and remove the §103(a) rejection.

The Examiner rejected claims 13, 33, 53, and 73 under 35 U.S.C. §103(a) as being unpatentable over Kaminsky in view of Cribbes and further in view of Endrenyi, Subramanyam, Cave, Stoughton et al. (US Patent Number 6,132,969) and Baleanu (US Patent Number 5,748,508). The Examiner added Stoughton et al. (hereinafter Stoughton) and Baleanu for their disclosure of generating goodness-of-fit metrics and collinearity diagnostics. Neither Stoughton nor Baleanu provide a teaching or motivation that suggests the desirability of performing a simulation of a distribution of future service events based on estimated time-to-failure distributions and performance life distributions derived from deterioration rate curves as set forth in claims 1, 22, 42 and 62. Since claims 13, 33, 53, and 73 depend from presumably allowable claims 1, 22, 42 and 62, respectively, Applicant submits that these claims are allowable by dependency and requests that the Examiner reconsider and remove the §103(a) rejection.

The Examiner rejected claims 14, 34, 54, and 74 under 35 U.S.C. §103(a) as being unpatentable over Kaminsky in view of Cribbes and further in view of Endrenyi, Subramanyam and Meester et al. (US Patent Number 5,686,359). The Examiner added Meester et al. (hereinafter Meester) for its disclosure of generating residual plots. Meester provides no teaching or motivation that suggests the desirability of performing a simulation of a distribution of future service events based on estimated time-to-failure distributions and performance life distributions derived from deterioration rate curves as set forth in claims 1, 22, 42 and 62. Since claims 14, 34, 54, and 74 depend from presumably allowable claims 1, 22, 42 and 62, respectively, Applicant submits that these claims are allowable by dependency and requests that the Examiner reconsider and remove the §103(a) rejection.

The Examiner rejected claims 15-16, 35-36, 55-56, and 75-76 under 35 U.S.C. §103(a) as being unpatentable over Kaminsky in view of Cribbes and further in view of Endrenyi and Kozam et al. (US Patent Application Publication Number 2002/0035570). The Examiner added Kozam et al. (hereinafter Kozam)

for its disclosure of performing a validation. Kozam provides no teaching or motivation that suggests the desirability of performing a simulation of a distribution of future service events based on estimated time-to-failure distributions and performance life distributions derived from deterioration rate curves as set forth in claims 1, 22, 42 and 62. Since claims 15-16, 35-36, 55-56, and 75-76 depend from presumably allowable claims 1, 22, 42 and 62, respectively, Applicant submits that these claims are allowable by dependency and requests that the Examiner reconsider and remove the §103(a) rejection.

The Examiner rejected claims 17, 37, 57, and 77 under 35 U.S.C. §103(a) as being unpatentable over Kaminsky in view of Cribbes and further in view of Endrenyi and Butler. The Examiner added Butler for its disclosure of using a statistical analysis with a deterioration rate analysis. As mentioned above, Butler provides no teaching or motivation that suggests the desirability of performing a simulation of a distribution of future service events based on estimated time-to-failure distributions and performance life distributions derived from deterioration rate curves as set forth in claims 1, 22, 42 and 62. Since claims 17, 37, 57, and 77 depend from presumably allowable claims 1, 22, 42 and 62, respectively, Applicant submits that these claims are allowable by dependency and requests that the Examiner reconsider and remove the §103(a) rejection.

The Examiner rejected claims 18-19, 38-39, 58-59, and 78-79 under 35 U.S.C. §103(a) as being unpatentable over Kaminsky in view of Cribbes and further in view of Endrenyi, Butler and Wang. The Examiner added Wang for its disclosure of generating life performance distributions from deterioration rate curves. As mentioned above, Wang provides no teaching or motivation that suggests the desirability of performing a simulation of a distribution of future service events based on estimated time-to-failure distributions and performance life distributions derived from deterioration rate curves as set forth in claims 1, 22, 42 and 62. Since claims 18-19, 38-39, 58-59, and 78-79 depend from presumably allowable claims 1, 22, 42 and 62, respectively, Applicant submits

that these claims are allowable by dependency and requests that the Examiner reconsider and remove the §103(a) rejection.

The Examiner rejected claims 20, 40, 60, and 80 under 35 U.S.C. §103(a) as being unpatentable over Kaminsky in view of Cribbes and further in view of Endrenyi, Butler, Wang and Moosa et al. (US Patent Number 5,822,218). The Examiner added Moosa et al. (hereinafter Moosa) for its disclosure of using the life performance distributions to determine a Weibull distribution. Moosa provides no teaching or motivation that suggests the desirability of performing a simulation of a distribution of future service events based on estimated time-to-failure distributions and performance life distributions derived from deterioration rate curves as set forth in claims 1, 22, 42 and 62. Since claims 20, 40, 60, and 80 depend from presumably allowable claims 1, 22, 42 and 62, respectively, Applicant submits that these claims are allowable by dependency and requests that the Examiner reconsider and remove the §103(a) rejection.

In view of the foregoing remarks and amendments, Applicant requests that the Examiner reconsider this application and allow claims 1-6, 9-16, 20-26, 29-36, 40-46, 49-56, 60-66, 69-76 and 80-81.

If the Examiner has any questions regarding the present patent application, the Examiner can call Applicant's attorney, David Goldman, at telephone number (518)-387-5927 or (518)-387-5903.

Respectfully submitted,

David Goldman

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Schenectady, New York
Dated: December 18, 2003